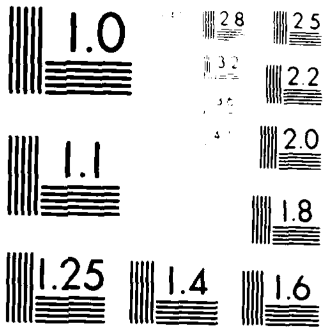
AD-A152 019 METEOROLOGICAL CONDITIONS AFFECTING ELECTROMAGNETIC PROPAGATION ON THE ARABIAN PENINSULA(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA W F PETERSEN SEP 84 1/2

UNCLASSIFIED F/G 20/14 NL



MICROCOPY RESOLUTION TEST CHART

AD-A152 019

NAVAL POSTGRADUATE SCHOOL

Monterey, California

DTIC
ELECTE
APR 4 1985
S A

THESIS

METEOROLOGICAL CONDITIONS AFFECTING
ELECTROMAGNETIC PROPAGATION
IN THE ARABIAN PENINSULA

by

[illegible]

[illegible]

[illegible]

[illegible]

DTIC FILE COPY

85 03 1[illegible] [illegible]03

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER / 2. GOVT ACCESSION NO. A152 019	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Meteorological Conditions Affecting Electromagnetic Propagation on the Arabian Peninsula	5. TYPE OF REPORT & PERIOD COVERED Master's Thesis September 1984
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Wayne Frederick Petersen	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93943	12. REPORT DATE September 1984
	13. NUMBER OF PAGES 135
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report)
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ducting
Electromagnetic Propagation
Dhahran, Saudi Arabia

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Modern U.S. Military radars and communication equipment performance will be strongly influenced by the environment it will be operating in. One of the most important atmospheric affects is ducting of electromagnetic energy by refractive layers in the atmosphere. To assess the affects of ducting on electromagnetic emissions around Dhahran, Saudi Arabia, a geometric optics model of wave propagation developed by Raymond P. Wasky was modified and utilized. This thesis also attempted

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

to show the correlation of wind direction and wind speed to the establishment, location and heights of ducts. Finally this thesis attempted to determine if there was any correlation between the occurrence of land-sea breezes and ducting.

Approved for public release, distribution unlimited.

Meteorological Conditions Affecting Electromagnetic Propagation on the Arabian Peninsula

by

Wayne F. Petersen
Captain, United States Army
B.S., Florida Institute of Technology, 1973

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING
(ELECTRONIC WARFARE)

from the

NAVAL POSTGRADUATE SCHOOL
September 1984

Author: ______________________________
Wayne F. Petersen

Approved by: ______________________________
Kenneth L. Davidson, Thesis Advisor

____
Jeffrey M. Knorr, Second Reader

____
John M. Bouldry
Chairman, Electronic Warfare Academic Group

____
David A. Schrady, Academic Dean

ABSTRACT

Modern U.S. military radars and communication equipment performance will be strongly influenced by the environment it will be operating in. One of the most important atmospheric affects is ducting of electromagnetic energy by refractive layers in the atmosphere. To assess the affects of ducting on electromagnetic emissions around Dhahran, Saudi Arabia, a geometric optics model of wave propagation developed by Raymond P. Wasky was modified and utilized. This thesis also attempted to show the correlation of wind direction and wind speed to the establishment, location and heights of ducts. Finally this thesis attempted to determine if there was any correlation between the occurrence of land-sea breezes and ducting.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

The United States (U.S.) Military anticipates fighting outnumbered in any future conflict. Since Vietnam, modernization of our forces has dragged, thereby permitting a decay in the readiness of our forces. At the same time, the Soviet Union has increased defense expenditures. The Soviets remain committed to their goal of world socialism and Soviet Policy proceeds on the basis of military power.

Country	1973	1979	1981
United States	78,472	114,503	171,000
Soviet Union	92,000	241,000	267,000

Figure 1: 'Defense Expenditures (thousand $) [Ref. 1, 2, & 3] '

Major Army unit commanders must be able to detect, track and destroy enemy targets deep in the enemy territory before they reach the forward-line-of-own-troops (FLOT). Our commanders must have the time to adjust their own forces to be able to meet the enemy on a more even combat ratio when the enemy reaches the FLOT. Thru an integrated collection effort and the use of sophisticated electronic equipment, it is the job of the intelligence community to find and locate the enemy. To accomplish the above, effective use of the electromagnetic spectrum is essential.

The performance of any electromagnetic system varies with the geographical region, topography, systems employment configuration and operating frequency. These performance

characteristics are recognized by most planners, however in addition to these parameters one must also consider meteorological elements. Most testing of electronic equipment is performed under normal conditions. This is a tactical shortcoming because extreme environmental conditions may have an adverse affect on a systems performance.

B. OBJECTIVE

The objective of this thesis is to determine the synoptic meteorological conditions that will severely affect electromagnetic (EM) propagation on the Arabian Peninsula. Atmospheric refractivity, surface and elevated ducts, and land-sea breeze will be addressed.

C. THE DESERT ENVIRONMENT

The desert environment was selected as a type of environmental/topographical region for examining the affects of extremes. Radiosonde data recorded in Dhahran, Saudi Arabia from 1978 to 1980 will be examined. The importance of this data is for several reasons. First, the desert areas of the world comprise approximately 19% of the earth's land mass. This is a significant portion of the total surface area available for ground combat. Saudi Arabia encompasses an area of 830,000 square miles, much of which is desert [Ref. 4]. Second, several of the desert regions of the world have a political and military significance because of their strategic location and valuable mineral deposits. The Arabian oil fields account for about one-half of the known reserves of the non-Communist world. They also supply about one-fifth of the world's total oil production [Ref. 5]. Saudi Arabia was the largest producer of crude petroleum in the Middle East and the third largest in the world in

Country	1974	1979	1980
Soviet Union	3,373,650	4,307,100	4,432,050
United States	3,202,585	3,111,625	947,905
Saudi Arabia	2,996,543	3,479,389	3,530,000
Iran	2,197,700	1,121,346	550,000
Venezula	1,086,333	860,072	793,397
Kuwait	894,781	602,000	912,610
Iraq	720,729	1,252,000	961,000

Figure 2: 'Crude Oil Production Comparisons (thousand 42-gal barrels) [Ref. 6, 7, 8, & 9]'

1980 [Ref. 10]. Thirdly, the desert has the most extreme cases of abnormal atmospheric refractivity. Fourthly, a worldwide analysis of upper atmospheric radiosonde data was performed by Ortenburger (GTE, Sylvania 1973). Results indicate that trade wind regions are the areas of significant ducting. One area of prevalent ducting was found in the upper Indian Ocean and Persian Gulf. The probability of ducting in this area is 60% [Ref. 11]. Finally, the dramatic increase of Soviet military power in Asia, the Pacific Ocean and the Indian Ocean is the most significant military development in recent years. The Soviets have replaced and upgraded equipment on their Southern Theater. Additionally, their 105,000 troops in Afghanistan have altered the balance of power in the Indian Ocean and Persian Gulf [Ref. 12].

II. GENERAL DISCUSSION, INTERRELATIONSHIPS AND EQUATIONS

A. REFRACTIVITY

The transmission of electromagnetic (EM) signals through a medium is affected by the absorption and re-emission of EM energy by the atomic and molecular elements of that medium. The dielectric constant (ϵ) best describes the interaction of the electric field with the medium. As the EM wave interacts with the new medium, its speed changes and is determined by:

$$V = \frac{c}{\sqrt{\epsilon}} \qquad \text{(EQN 1)}$$

where c is the velocity in the vacuum and v is the velocity in the medium. Rather than deal with a velocity, physicists defined a new parameter "Index of Refraction" (n) where

$$n = \frac{c}{V} = \sqrt{\epsilon} \qquad \text{(EQN 2)}$$

A measure of the amount of refraction experienced by a ray as it passes through a surface which separates two media of different densities is designated "n". It is the ratio of the wavelength or velocity of an EM wave in a vacuum to that in the new medium. When the EM wave passes from one medium to another non-absorbing medium, the angle of incidence θ_1 and the angle of refraction θ_2 (See Figure 3) are related by the principles of Snell's Law:

$$\frac{\sin \Theta_1}{\sin \Theta_2} = \frac{n_2}{n_1} \qquad \text{(EQN 3)}$$

The Index of Refraction of a vacuum is one; of air is approximately 1.000326; and, for water approximately 1.33.

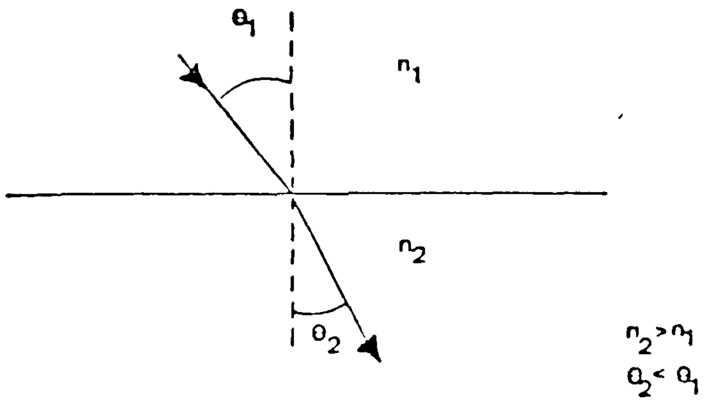


Figure 3: 'Refraction of Incident Rays [Ref. 13]'

The relationship of the index of refraction to the atmospheric pressure (P), water vapor pressure (e), and temperature (T) is given by the following equation:

$$(n-1) = \left(77.6\frac{P}{T} - 5.6\frac{e}{T} + 3.75\times 10^{5}\frac{e}{T^2}\right)\times 10^{-6} \qquad \text{(EQN 4)}$$

where atmospheric pressure and the water vapor pressure are in millibars and temperature is in degrees Kelvin. The resulting values of the index of refraction are awkward. Therefore a new parameter "N", which is the refractivity, is defined for convenience as follows:

$$N = (n-1)\times 10^{6} \qquad \text{(EQN 5)}$$

Thus,

$$N = 77.6\frac{P}{T} - 5.6\frac{e}{T} + 3.75\times 10^{5}\frac{e}{T^2} \qquad \text{(EQN 6)}$$

[Ref. 14].

B. MODIFIED REFRACTIVITY

The use of refractivity to depict refraction is difficult. Ducting conditions are identified by determining its change with height. In a normal situation, the refractivity decreases with height. The refractivity may be mathematically modified so that when its gradient (dN/dZ) is applied to EM propagation over a hypothetical flat earth it is essentially equivalent to the propagation over the real curved earth with the actual refractivity.

The Modified Refractive Index, M, adds 157 N-units per kilometer to all N-values. It is defined as:

$$M = N + 157 Z \qquad \text{(EQN 7)}$$

where N is the value of refractivity at any height Z, and Z is in kilometers. M will increase with height in the standard atmosphere. Also, when the M-gradient (dM/dZ) is zero the ray curvature is equal to the real earth's curvature. M versus height profiles are mainly used to obtain ducting information (See Chapter II, Section D). [Ref. 15]

C. DN/DZ AND DM/DZ

An important description of refractivity is not its value but its gradient. Refractivity is a multi-variable parameter and thus an expression for its gradient is:

$$\frac{dN}{dz} = \frac{\partial N}{\partial P}\frac{\partial P}{\partial z} + \frac{\partial N}{\partial T}\frac{\partial T}{\partial z} + \frac{\partial N}{\partial e}\frac{\partial e}{\partial z} \qquad \text{(EQN 8)}$$

For an average standard condition, dN/dZ is approximately -40 per Km. In ray tracing problems, the gradient dM/dZ can be used to obtain a ray path curvature that is relative to the curvature of the earth.

Classification	dN/dZ (/Km)	dM/dZ (/Km)	Range
Subrefraction	>0	>157	Reduced
Normal	0 to -79	79 to 157	Normal
Super Refraction	-79 to -157	0 to 79	Increased
Trapping	<-157	<0	Increased

Figure 4: 'N & M Gradients [Ref. 16] '

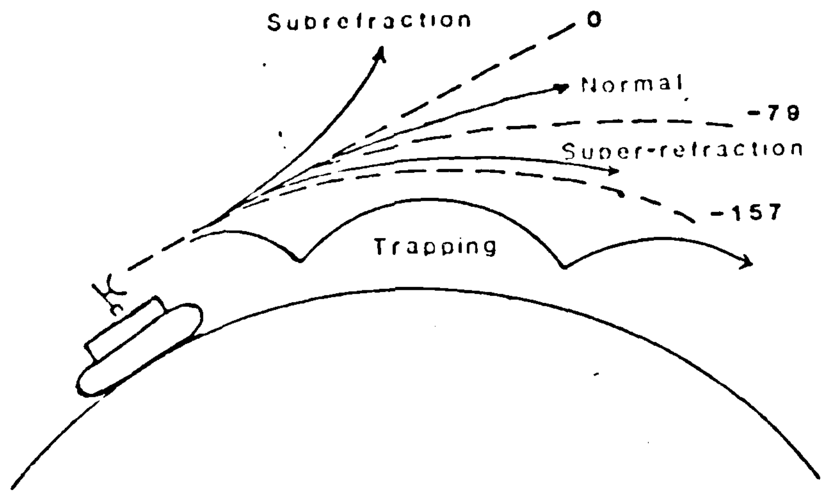


Figure 5: 'N Gradient Pictorial [Ref. 17] '

Standard (normal) propagation results in a ray curvature due to refraction which has a value approximately one-fourth that of the earth's curvature. This is equivalent to the straight line propagation over a hypothetical earth whose radius is four-thirds the radius of actual earth. Subrefraction produces a less than normal downward bending or

even an upward bending of radio waves as they travel through the atmosphere. Thus, radar and radio coverage is decreased. Super refraction produces a greater than normal downward bending of radio waves as they travel through the atmosphere. This results in extended radio horizons and increased radar coverage. Strong super refraction can produce skip effects in elevated layers or the troposphere. Skip effects occasionally make it possible to detect targets at distances greater than the normal horizon while closer targets remain undetected.

D. DUCTING

A duct is a shallow, almost horizontal layer in the atmosphere where EM energy is trapped. The trapping layer is where $dN/dZ < -157$ Km and thus the ray will be bent toward the earth. The trapping layer is the top of the duct. Energy transmitted within the duct will be partially confined and channeled between the top and bottom of the duct. Ducting occurs in several ways and can best be categorized by the altitudes at which they are found:

Surface Ducts -average height less than 1,500 feet;

Elevated Ducts-average height 5,000 to 10,000 feet;

Evaporation Ducts-approximately 100 feet.

Evaporation ducts only occur over water.

These duct types are defined by Figures 6 thru 8. The top of a duct corresponds to a height above the surface where the M value is a minimum. The duct base corresponds to the height at which a vertical line drawn downward from the point of minimum M value first intersects a point of equal M units or the surface. Radar targets may be detected at long ranges if both target and radar are in the duct. The area just above a duct may have reduced radar coverage. An aircraft or missile flying just above the duct might not be detected until very close to the radar, if at all.

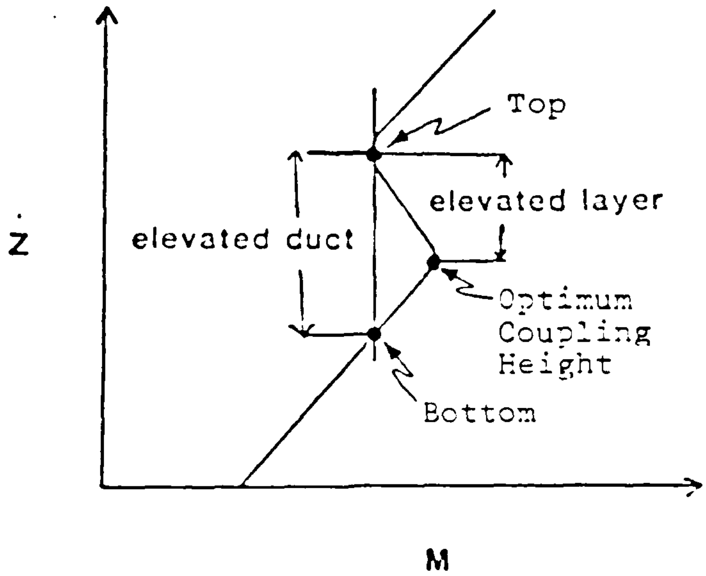


Figure 6: 'Elevated Duct
[Ref. 18]'

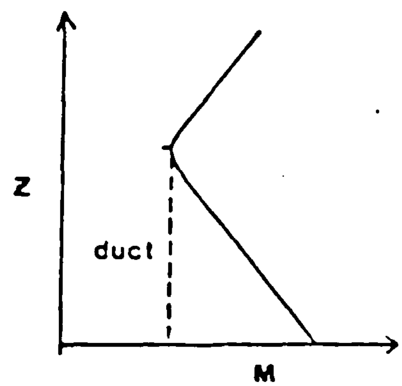


Figure 7: 'Surface
Based Duct Caused by Surface Layer
[Ref. 19]'

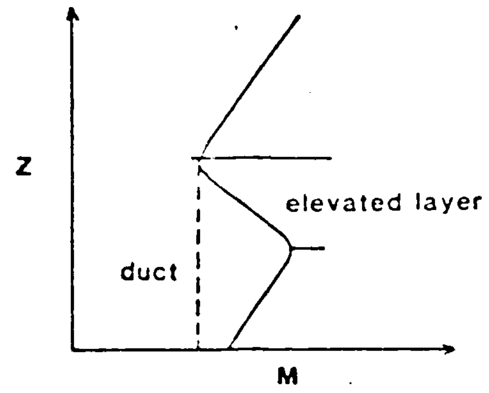


Figure 8: 'Surface Based Duct Caused by an Elevated Layer [Ref. 20] '

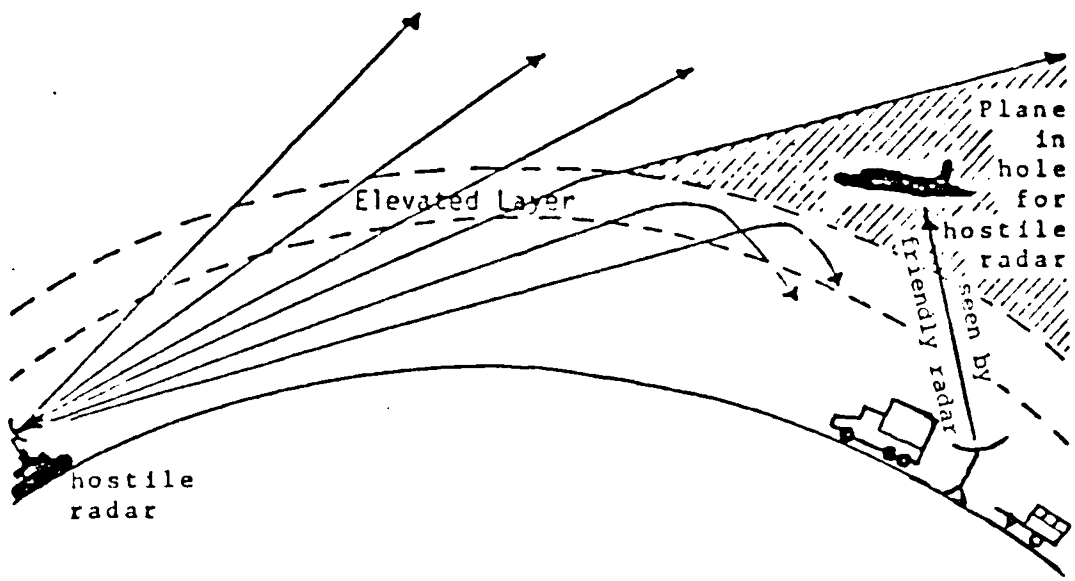


Figure 9: 'Radar Hole [Ref. 21] '

A duct will trap EM energy for only a selected frequency range. Minimum trapping frequencies have been established because the limit is on the low side. The minimum frequency that will be trapped is given by:

$$f_m = 3.6033 \times 10^{11} \, d^{-(3/2)}, \text{ Hz} \qquad (\text{Eqn } 9)$$

where d is the thickness of the duct in meters. [Ref. 22]

E. LAND-SEA BREEZE

The land-sea breeze is the complete cycle of the day-night local winds occuring on sea coasts due to the differences in surface temperature of the land and sea. The land breeze component of the system blows from land to sea and the sea breeze blows from sea to land.

The basic principle of the sea breeze is that during the day the land and the air over the land gets heated considerably, while the air over the sea changes slightly. The warm, light air over the land then rises and is replaced by the cooler air from the sea. The day time sea breeze surpasses in intensity the night time land breeze. The direction of the sea breeze does not remain constant during the course of the day. The gradual change in the direction of the sea breeze appears because of the affect of the Coriolis Force.

At night the wind direction reverses, because the air over the land becomes cooler than the sea air. Now it is the sea air which rises and the cooler land air that moves out from the land as a land breeze. [Ref. 23]

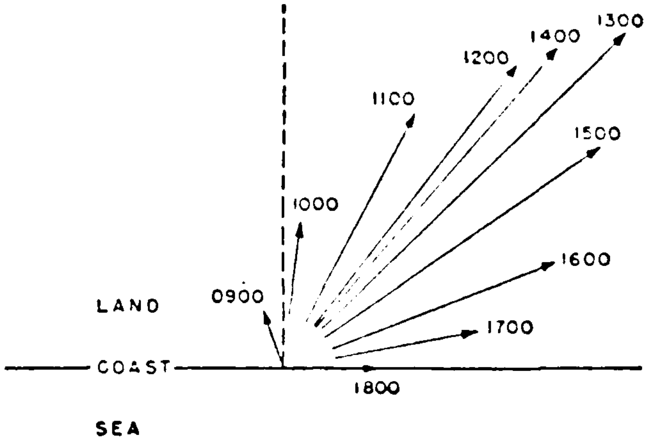


Figure 10: 'Hourly Variation of Relative Wind Velocity at Hoek van Holland 31 July 1938 [Ref. 24]'

III. SAUDI ARABIAN WEATHER

A. THE COUNTRY

Saudi Arabia occupies approximately four-fifths of the Arabian Peninsula (see Figure 11). It is about the size of the United States east of the Mississippi. The Arabian Peninsula is a plateau which slopes slightly toward the east. It contains both the world's largest sand desert, the Rub al-Khali, and maybe the world's largest oasis, al-Hasa. In addition to the Rub al-Khali, or "Empty Quarter", the other two sand areas are the Great Nufud Desert and the Dahana Desert. Outside these deserts the surface is gravel, or in the case of the west-central area the surface consists of crumbled beds of lava. [Ref. 25]

B. CLIMATOLOGY

Saudi Arabia has a desert climate characterized by extreme heat during the day with an abrupt drop in temperature at night and, a small but erratic rainfall. Along the coastal regions of the Red Sea and the Persian Gulf the desert temperature is moderated by the closeness of those bodies of water. Temperatures seldom go over 100°F, but the relative humidity is usually over 85 percent. This combination produces a hot mist during the day and a warm fog at night. In Najd and the deserts a uniform climate prevails. The average temperature is 112°F. Readings of up to 130°F are common. In the winter the temperature seldom drops below 32°F, however, the almost total absence of humidity and high wind-chill factor make for a cold atmosphere. In spring and autumn the temperatures average 85°F. Along the western and eastern coastal strips the prevailing winds are from the northern quadrant. A southerly wind is accompanied

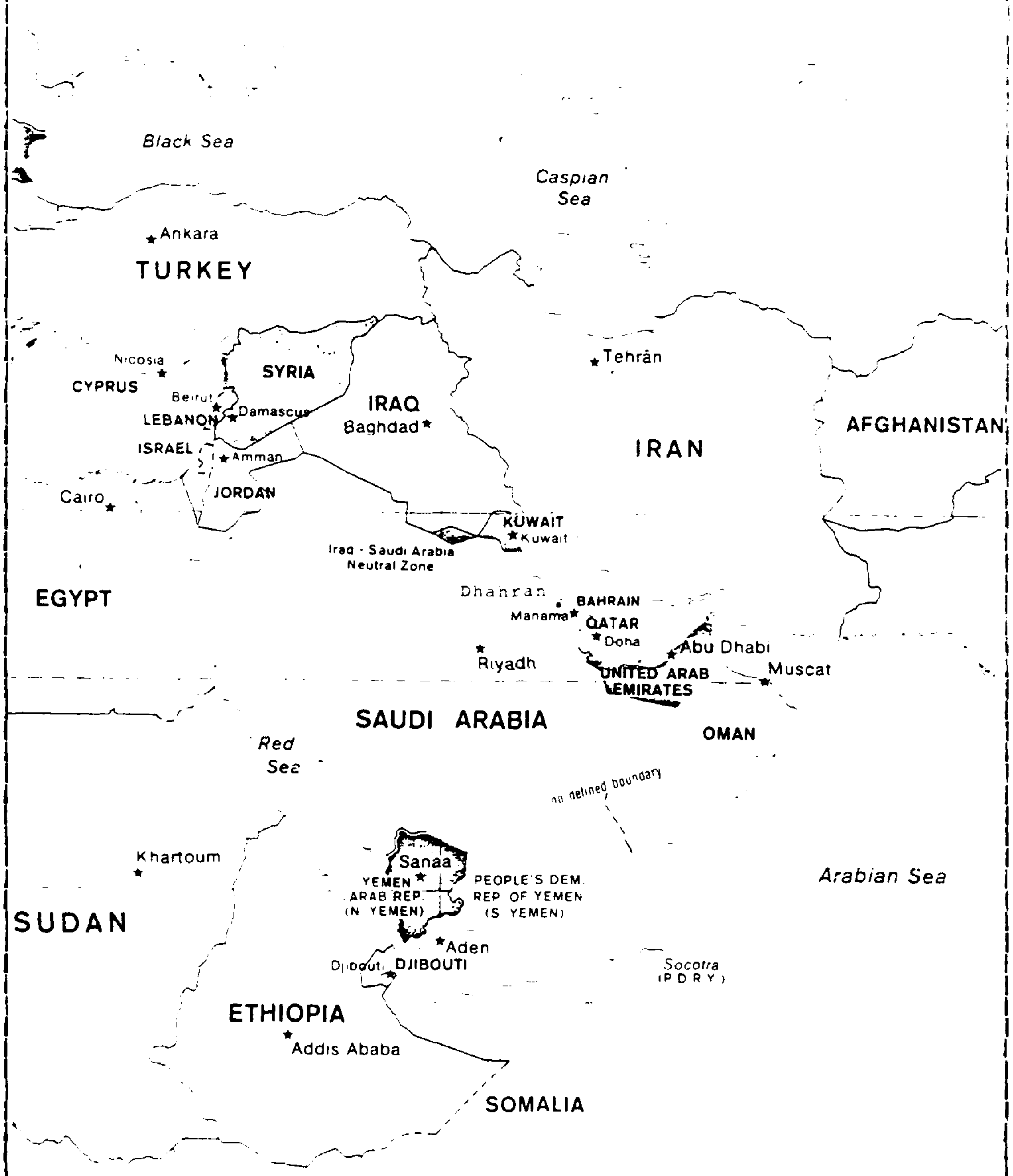


Figure 11: 'Arabian Peninsula'

Month	Daily Temperature (°F)	(°K)	Monthly Precipitation (in inches)	Days of Thunder-storms
January	60.8	289	0.91	0.44
February	66.2	292	0.63	0.44
March	72.9	296	0.16	0.56
April	79.0	299	0.51	1.44
May	88.5	304	0.08	0.22
June	94.5	308	0.04	0.00
July	95.9	309	0.00	0.00
August	96.3	309	0.00	0.00
September	92.5	307	0.00	0.00
October	83.7	302	0.08	0.11
November	73.8	296	0.28	0.67
December	63.5	291	0.16	0.00

Figure 12: 'Mean Temperatures and Precipitation Values [Ref 26 & 27]'

by an increase in temperature and humidity and by a particular kind of storm known in the Persian Gulf area as "kauf". In late spring and early summer a strong northwesterly wind called a "shamel", blows particularly severe in eastern Arabia. The shamel produces sand and dust storms.

Month	N	NE	E	SE	S	SW	W	NW	Calm
January	0	0	0	0	0	0	0	70	0
April	30	30	20	10	0	0	0	0	0
May	10	4	6	4	2	6	25	33	10
July	60	10	10	0	0	0	0	20	0
October	10	5	6	6	5	5	20	31	12

Figure 13: 'Surface Wind Data Analysis for Dhahran [Ref. 28 & 29]'

In winter, the Mediterranean cyclones (lows) moving west to east in association with upper troughs and jet streams, are considered the main rain producing systems. The distribution of winter rainfall shows maximum values in the peninsula's northern part and a gradual decrease in the lowlands

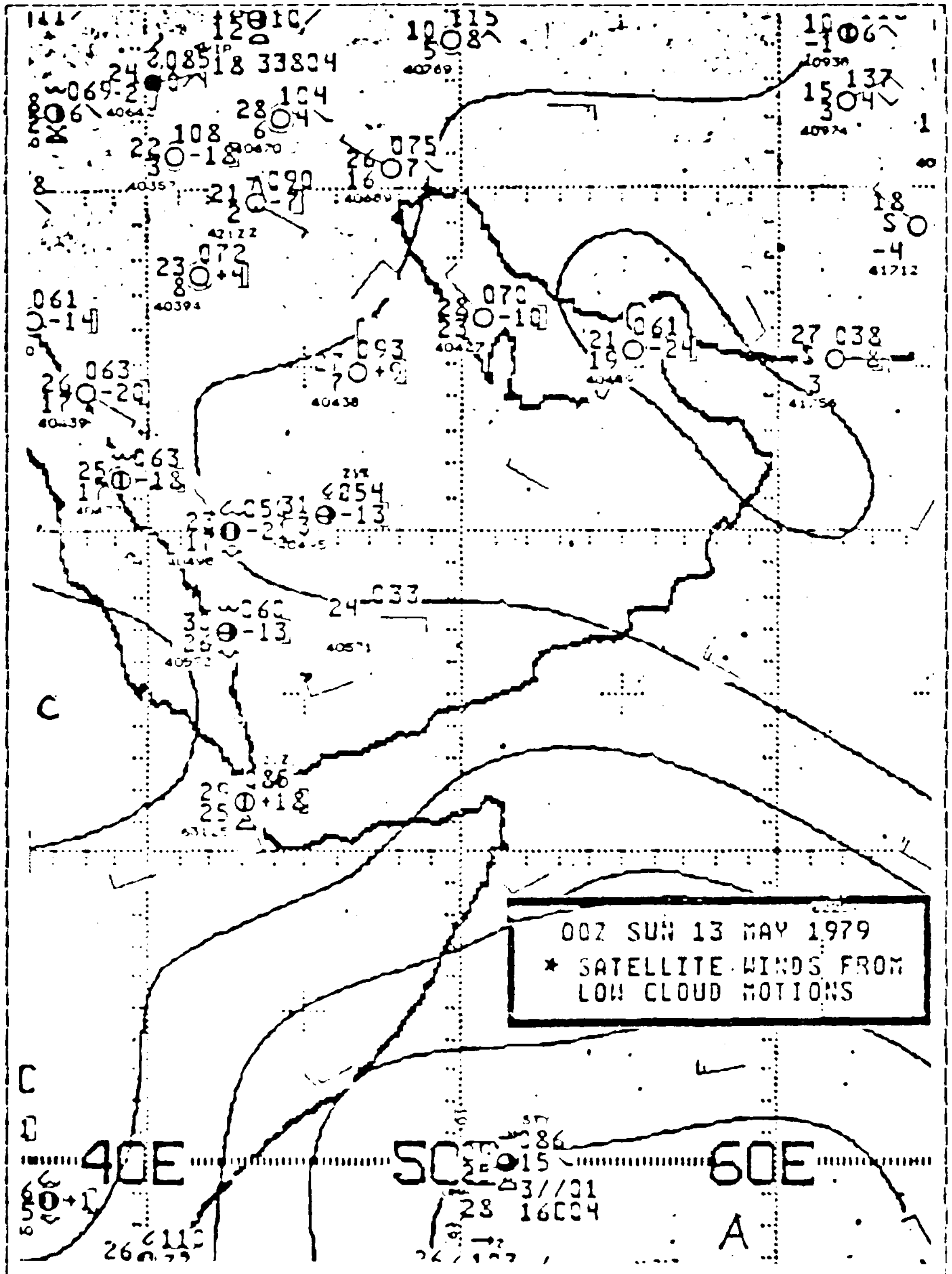


Figure 14: 'Typical May Weather Map'

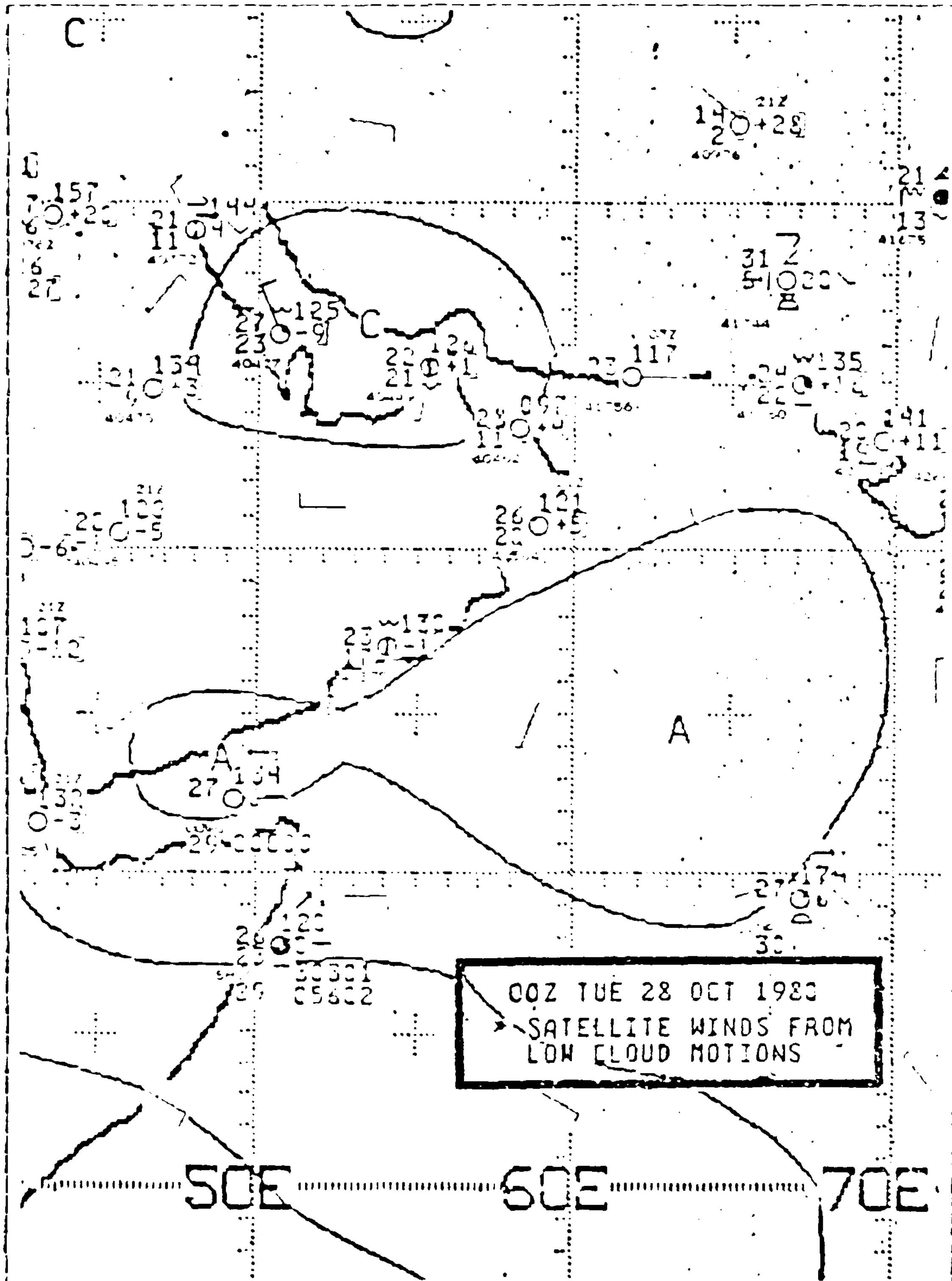


Figure 15: 'Typical October Weather Map'

on the eastern and western sides. In the spring, the Mediterranean cyclones continue to affect the north. Spring is also characterized by weak stability in the lower atmospheric layers and large daytime differences between land and water surfaces. These conditions stimulate active local circulations between land and sea, and between mountains and valleys particularly in the southwest. In summer, the thermal monsoon trough is established across the peninsula. Thus rainfall is restricted to the peninsula's southwest while the northern part is dry. In autumn, middle latitude disturbances begin to affect the northern portion of the peninsula but local circulation is weak therefore there is only minor concentrations of rainfall in the north. The frequency of thunderstorms on the Arabian Peninsula is related to the rainfall distribution. There is a higher frequency distribution of thunderstorms near the eastern and western coasts than in the interior areas. [Ref. 30]

C. SYNOPTIC CONDITIONS

The weather situation during the months of May and October for 1978, 1979, and 1980 in Dhahran, Saudi Arabia will be overviewed in this section. Information was taken from weather maps provided by the Naval Postgraduate School Meteorological Department. Data from radiosonde launches at Station 40427, Bahrain Muharraq, were utilized. Bahrain Muharraq is located approximately 25 miles east of Dhahran. It should also be noted that all watches in Saudi Arabia are reset at sundown. The information posted on the weather maps utilized the Zulu Time Zone System. Saudi Arabia falls into the Delta time zone, thus 0000Z is 0400D or 4 o'clock in the morning.

Figures 16 and 17 show the pressure, temperature and dew point averages for 1978, 1979, and 1980. Mean daily temperatures differed slightly from history (see Figure 12). May

Time	YR	Pressure (mb)	Temperature (°C)	Dew Point (°C)
0000Z / 0400D	78	5.6	26.8	20.1
	79	7.9	26.0	23.4
	80	6.4	27.3	20.9
1200Z / 1600D	78	6.2	32.2	17.9
	79	8.3	33.0	21.4
	80	6.1	30.8	20.3
0000Z / 0400D	Ave	6.6	26.7 (80.1°F)	21.5
1200Z / 1600D	Ave	6.9	32.0 (89.6°F)	19.9

Figure 16: 'May 1978, 1979, & 1980 Pressure, Temperature and Dew Point Averages'

Time	YR	Pressure (mb)	Temperature (°C)	Dew Point (°C)
0000Z / 0400D	78	11.3	26.5	23.6
	79	12.3	29.2	25.2
	80	10.9	27.2	23.9
1200Z / 1600D	78	10.9	31.9	21.3
	79	12.3	32.3	22.8
	80	10.9	31.7	22.1
0000Z / 0400D	Ave	11.5	27.6 (81.5°F)	24.2
1200Z / 1600D	Ave	11.4	32.0 (89.6°F)	22.1

Figure 17: 'October 1978, 1979, & 1980 Pressure, Temperature and Dew Point Averages'

had a mean of 84.7°F (29.3°C) which was 4°F cooler than the norm. October had a mean of 85.8°F (29.9°C) which was 2°F warmer than normal.

Cyclones predominantly (45%) affected the area during the month of May. Anticyclones were only in the area 8% of the time. However, during May 1979 anticyclones affect was 12%. During October 1979 and 1980, cyclones dominated the area 30% of the time. In October 1978, anticyclones were present

33% of the time while cyclones only 2%. Also during October haze was present 52% of the time. Apart from the two exceptions these percentages are consistent with the climatology of the Dhahran- Bahrain Muharraq area since Mediterranean cyclones affect the northern portion of the peninsula during spring and late autumn.

Figures 18 and 19 show that 50% of the time the winds were out of the north and northwest. Winds out of the southern quadrant were occasionally seen at 0000Z in both May and October but were absent at 1200Z. Winds out of the north and northwest were the strongest averaging 11 knots (see Figure 20).

Time	YR	N	NE	E	SE	S	SW	W	NW	Calm
0000Z / 0400D	78	29	4	0	8	8	13	4	33	0
	79	17	7	0	21	3	17	14	17	3
	80	16	0	0	5	5	16	11	42	5
1200Z / 1600D	78	38	19	4	0	0	0	0	39	0
	79	19	42	0	19	0	0	0	19	0
	80	25	12	19	0	0	0	0	44	0
	Ave	24	15	3	10	3	8	5	31	1

Figure 18: 'May 1978, 1979, & 1980 Wind Direction (%)

Time	YR	N	NE	E	SE	S	SW	W	NW	Calm
0000Z / 0400D	78	8	8	4	3	17	17	17	13	8
	79	19	7	4	15	19	4	7	26	0
	80	7	0	0	7	17	14	17	35	3
1200Z / 1600D	78	22	33	7	4	7	0	4	22	0
	79	45	14	10	3	0	0	0	28	0
	80	31	7	3	7	0	0	3	48	0
	Ave	22	12	5	7	10	5	8	29	2

Figure 19: 'October 1978, 1979, & 1980 Wind Direction (%)

Month	N	NE	E	SE	S	SW	W	NW
May	13	9	10	6	3	7	6	12
October	10	7	7	7	5	4	6	11

Figure 20: 'May and October 1978, 1979, & 1980 Wind Speed (Knots) Averages'

Ducting phenomenon for 1978, 1979, and 1980 is presented in Chapter IV. For comparative purposes results of two Radiosonde Data Analysis Projects by GTE Sylvania, Inc. are included here. These projects covered the years 1966 to 1969 and 1973 to 1974. Radiosonde data from Station 40427, Bahrain Muharraq, provided by the USAF Environmental Technical Applications Center (ETAC) was utilized by GTE Sylvania, Inc. to obtain their results. Both duct and super-refracting layer (SRLR) gradients (dN/dZ < -100 N units/Km) are depicted on the following graphs.

Figures 21 thru 28 reflect the following results for the months of May and October:

	May	October
1. Percent Occurrence Elevated Layers	10%	25%
2. Minimum Trapping Frequency for Elevated Ducts	400 MHz	200 MHz
3. Percent Occurrence Surface Layers	85%	65%

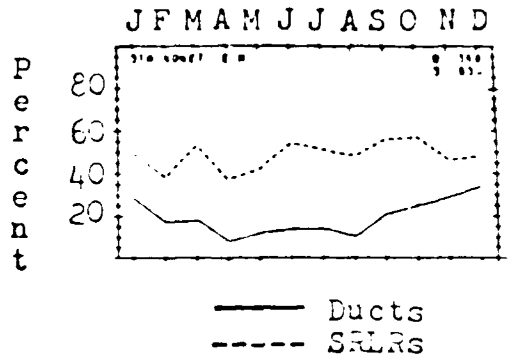


Figure 21: 'Percent Occurrence Elevated Layers [Ref. 31]'

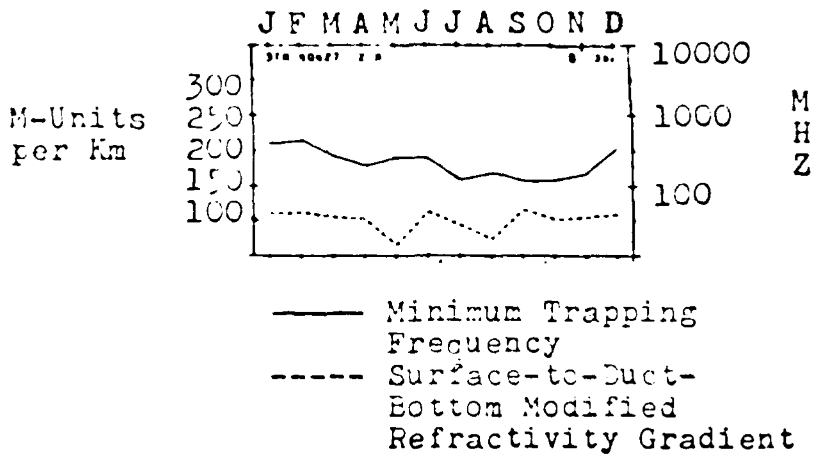


Figure 22: 'Minimum Trapping Frequency and Surface to Duct Bottom Modified Refractivity Gradient for Elevated Ducts [Ref. 32]'

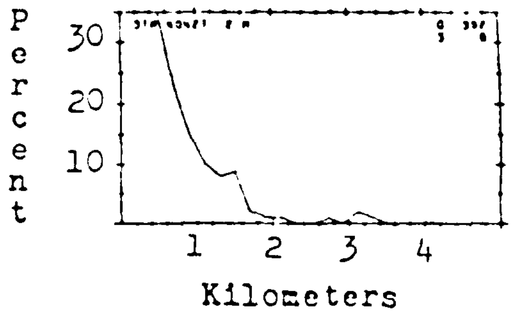


Figure 23: 'Coverage Height Elevated Layers [Ref. 33]'

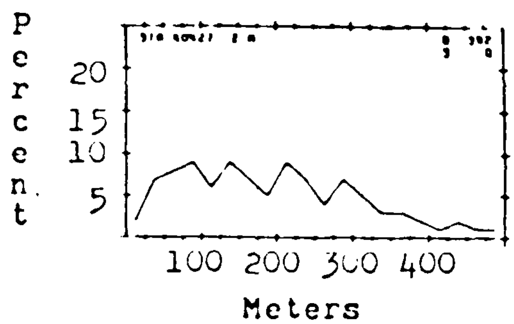


Figure 24: 'Thickness Elevated Layers [Ref. 34]'

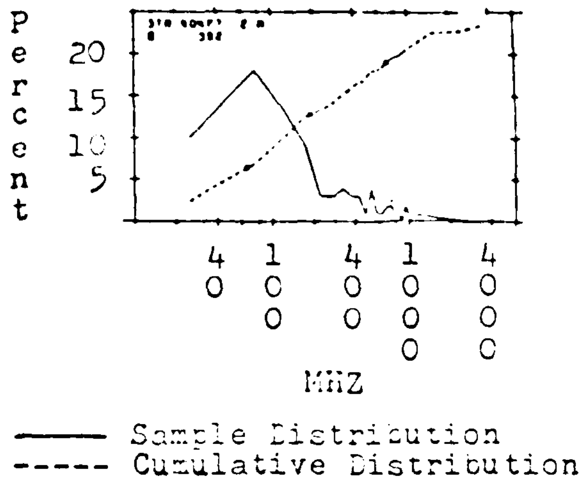


Figure 25: 'Minimum Trapping Frequency Elevated Ducts [Ref. 35]'

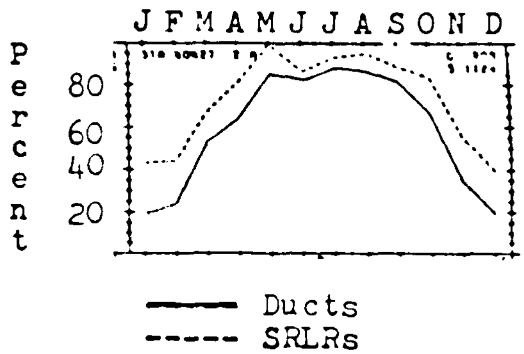


Figure 26: 'Percent Occurrence Surface Layers [Ref. 36]'

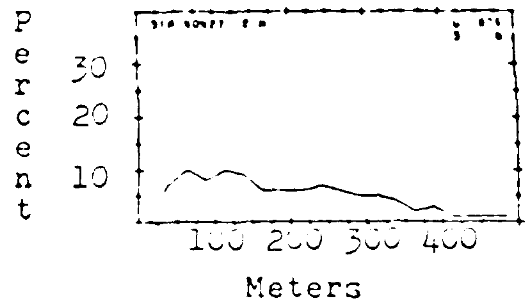


Figure 27: 'Thickness Surface Layers [Ref. 37]'

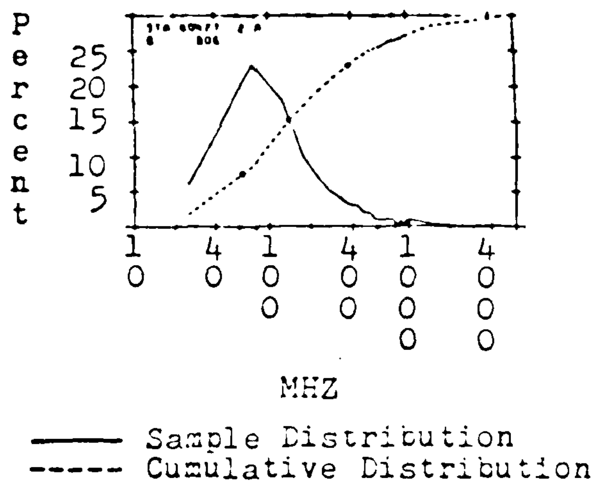


Figure 28: 'Minimum Trapping Frequency Surface Ducts [Ref. 38]'

IV. MODEL PERFORMANCE

A. DATA DESCRIPTION

Radiosonde data recorded at 1200Z (1600 Hours local) and 0000Z (2400 Hours local) on each day of May and October for 1978, 1979, and 1980 were utilized for this study. This data was obtained from the U.S. Air Force Environmental Technical Applications Center (ETAC) at Scott Air Force Base, Illinois.

This raw data had to be manipulated into a manageable form first. Utilizing the Naval Postgraduate School IBM 3033 Computer the data for each radiosonde launch was organized and cut off at the 100 millibar pressure level. This corresponded to a maximum altitude of approximately 16500 meters (54000 feet). Next, for each observation the refractivity, modified refractivity, dN/dZ, and dM/dZ were computed. Each launch record was then examined to determine if ducting was present. For each launch recording where ducting was probable a plot of N, a plot of M, a ray trace, and a plot of power density were done. Comparing the modified refractivity plots and also the ray traces nine (9) distinct groupings were established for further analysis.

The computer program utilized in this thesis was developed by Raymond P. Wasky. He developed the model to analyze the effects of atmospheric refraction on the field strength of radio emitters. He wrote the program in extended FORTRAN language for the CDC 6600 digital computer system. In his own words:

> This program is a geometric optics model of wave propagation through an inhomogeneous atmosphere having a vertically stratified index of refraction. The program calculates the direction of wavefront propagation by solving the

Euler-Lagrange equations of rays normal to incremental surfaces. The ray trajectories are then used to compute the relative emitter field strength or power density (normalized to free space) as a function of altitude and distance along the earth's surface. Fields which are reflected from the earth are attenuated by a Fresnel reflection coefficient and a surface roughness factor. The elevation angle and time of propagation are calculated along each ray path to determine the direction of the wavefront propagation vector and the phase relationship between interfering wavefronts for the field strength and power density computations. [Ref. 39]

Jim Blake, a student at the Naval Postgraduate School, converted this program for operation on the IBM 3033 computer system. The program was further modified for use in this study to include plotting of "M" and "dM/dZ" versus height. The model is applicable to propagation above 30 MHz. Given an isotropic emitter of known frequency, polarization, pulse width, and altitude the "N", "dN/dZ", "M", "dM/dZ" and free space normalized power density and relative field strength are calculated as a function of altitude and distance along the earth's surface. In the ray trajectory diagrams an artificial upward curvature of the rays is present due to plotting the earth's surface along a linear rather than curved axis.

The following parameters were utilized in running the program:

Frequency .... : 2900 MHz or 9800 MHz
Pulse width .... : 6.5 μsec or 1340 μsec
Transmitter height (above sea level): 90 ft
(above ground level): 15 ft
Emitter Polarization .... : Vertical
Earth Surface Type .... : Very Dry Land (Type 2)
Standard Deviation in Height ...... : Smooth Plain (Type 3)

Figures 35, 39, 43, 47, 51, 55, 59 and 63 present height gain curves computed at 2900 MHz for a 15 foot high emitter (the approximate height of an antenna on top of a tracked vehicle). Vertical reference axes are drawn at 20 nautical

mile intervals to represent the zero dB gain level of field strength relative to free space values. A scale for measuring relative field strength is given in the upper right corner of each plot.

Wind direction symbology (i.e. N for north, S for south, E for East, etc.) was assigned based on the following:

Radiosonde Wind Direction Reading (Degrees)	Assigned Direction Symbol
338 - 22	N
22 - 68	NE
68 - 112	E
112 - 158	SE
158 - 202	S
202 - 248	SW
248 - 292	W
292 - 338	NW

B. SURFACE AND ELEVATED DUCTS

Atmospheric Refractivity provided nine (9) distinct groupings for comparison. The first eight groupings have some form of ducting. The ninth group is the composite listing of all radiosonde launches which showed no ducting present. The three sets of surface based ducts caused by a surface layer are defined in Figure 29. The numbers depicted are the averages taken from the data/findings within each group/set.

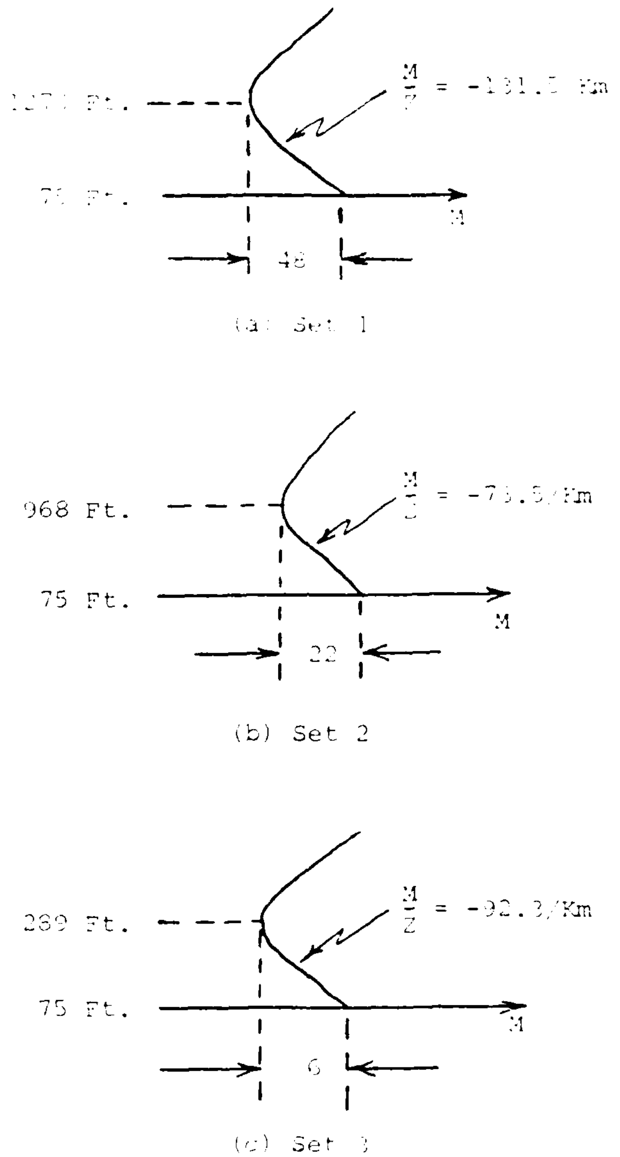


Figure 29: 'Surface Based Ducts Caused by Surface Layer'

The three types of surface based ducts caused by an elevated layer are defined in Figure 30.

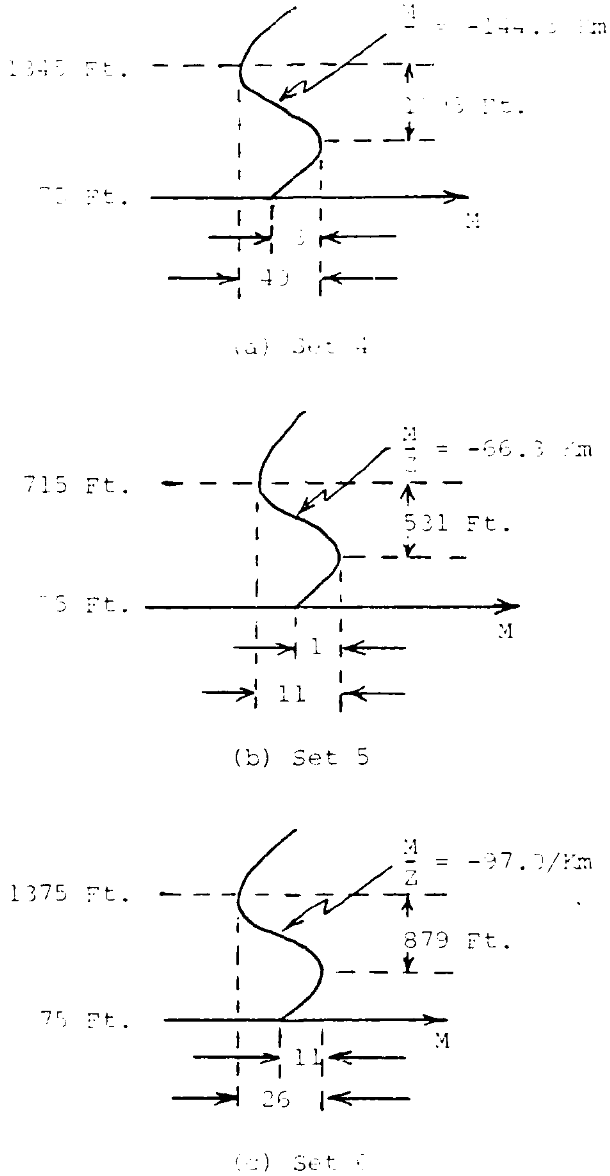
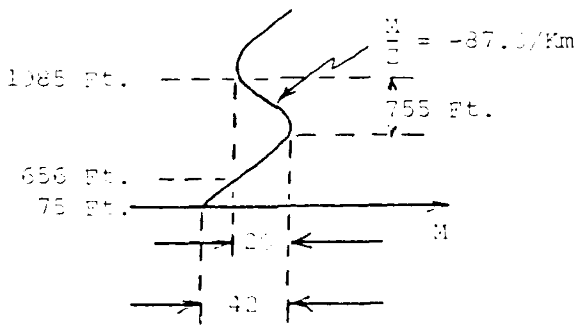
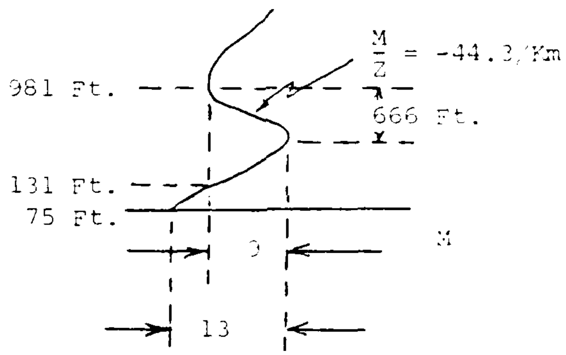


Figure 30: 'Surface Based Ducts Caused by Elevated Layer'

The two types of elevated ducts are defined in Figure 31.



(a) Set 7



(b) Set 6

Figure 31: 'Elevated Ducts'

Set 1 is pictorially represented by 28 May 79 0000Z in the following figures. The height of the surface based duct averaged approximately 1195 feet. The intensity of the duct was approximately 48 M-units. There were too few data recordings to determine a dominant wind direction at the 75-400 feet and 3000-4000 feet levels. A Northwest wind was dominant at the 4000-5250 feet level. The minimum trapped frequency for this set was 51.8 MHz. This occurred 5% of the time compared to the 15% of Figure 28.

Figure 34 shows that ray trapping occurs mainly between the earth's surface and 1100 feet. The area above the duct shows a distinct absence of rays. This would be considered the radar hole. While geometric optics predicts that there is no field present in this region, geometric optics is not able to solve for diffracted fields or fields resulting from leaky modes which are often present in atmospheric ducts.

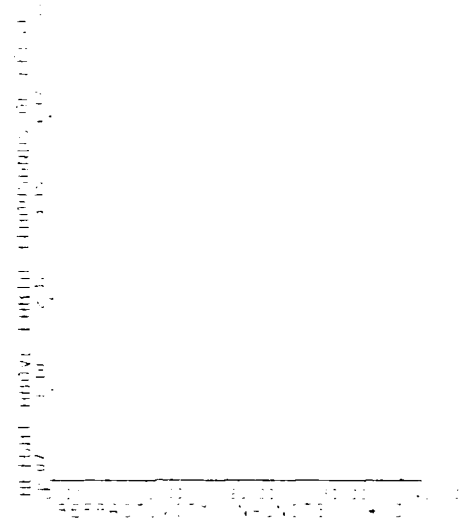


Figure 32: 'Atmospheric Refractivity Profile - 28 May 79 0000Z'

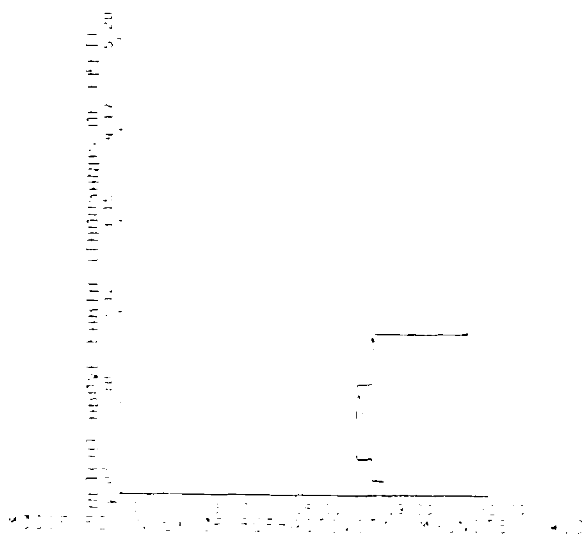


Figure 33: 'Modified Refractivity Profile - 28 May 79 0000Z'

Figure 34:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA 28 MAY 79, 0000Z

HO = 90 FT RAY ANGLES: 0.5 TO 0.5 DEGREE FRQ: 2900 MHZ

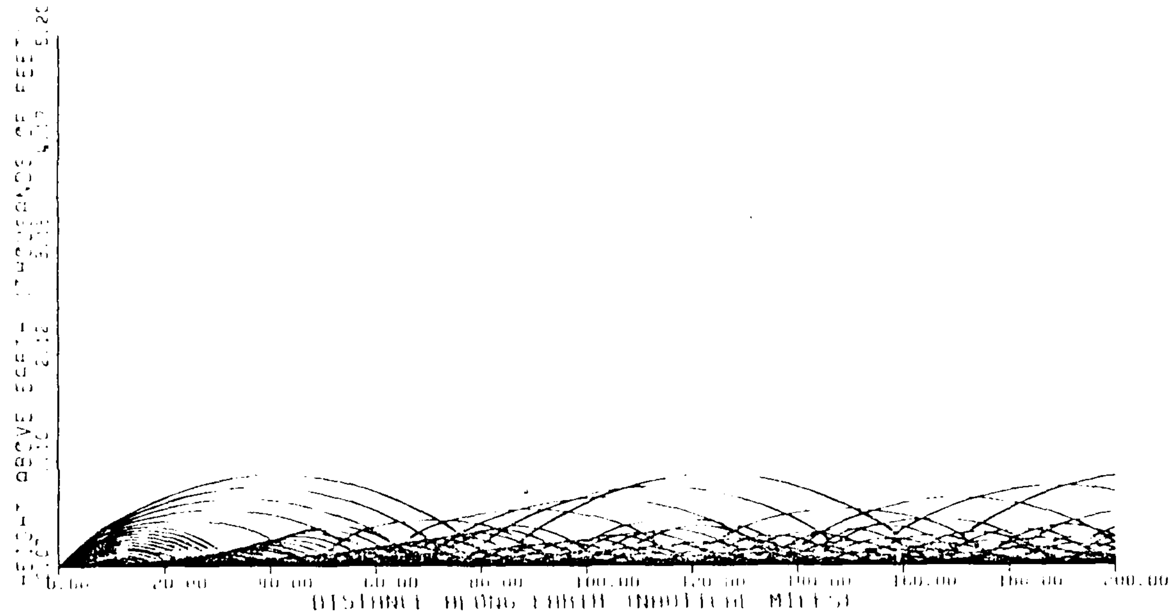
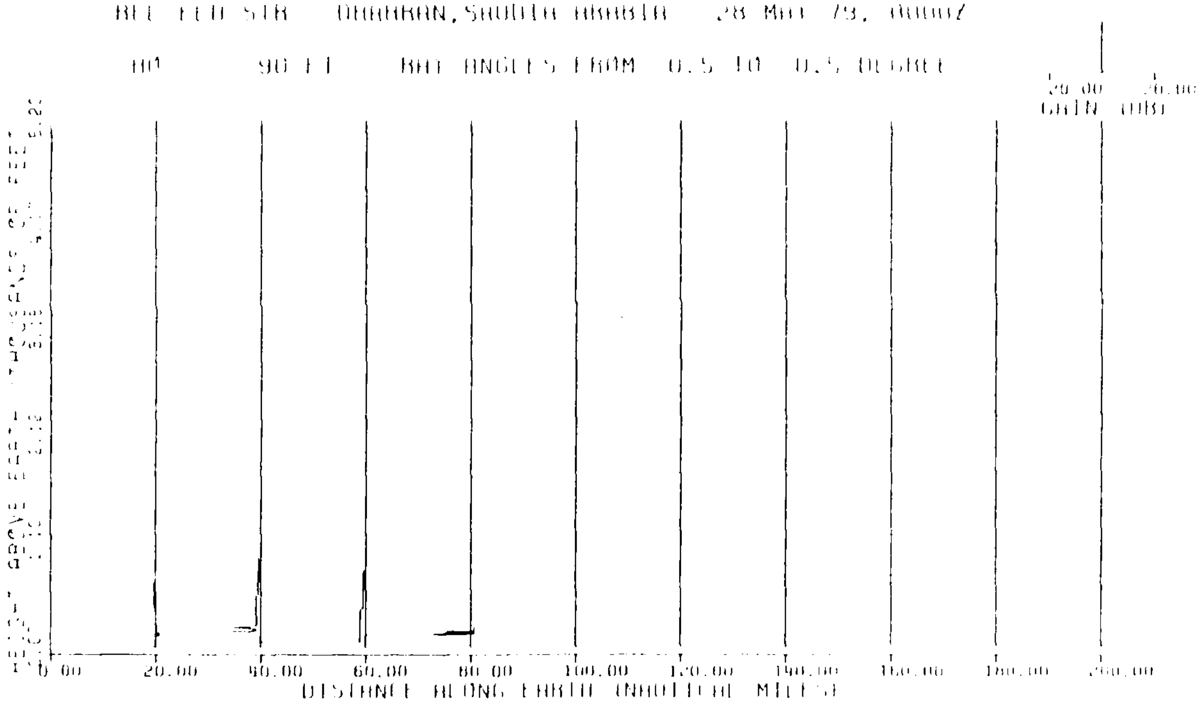


Figure 45:

REL FLD STR DHAHRAN, SAUDIA ARABIA 28 MAR 79, 0000Z

HT 90 FT RAY ANGLES FROM 0.5 TO 0.5 DEGREE



Set 2 is pictorially represented by 24 May 80 0000Z in the following figures. The height of the surface based duct averaged approximately 893 feet. The width of the duct was approximately 22 M-units. West and Northwest winds at the 75-400 feet level, North and Northwest winds at the 3000-4000 feet level, and North and Northwest winds at the 4000-5250 feet level were dominant. The minimum trapped frequency for this set was 80.2 MHz. This occurred 12% of the time compared to the 22% of Figure 28.

Figure 38 shows that ray trapping occurs mainly between the earth's surface and 700 feet. The area above the duct shows a radar hole extending from 70 to 200 nautical miles.

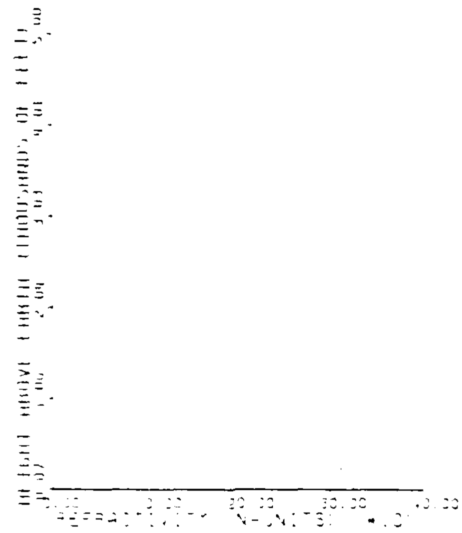


Figure 36: 'Atmospheric Refractivity Profile - 24 May 80 0000Z'

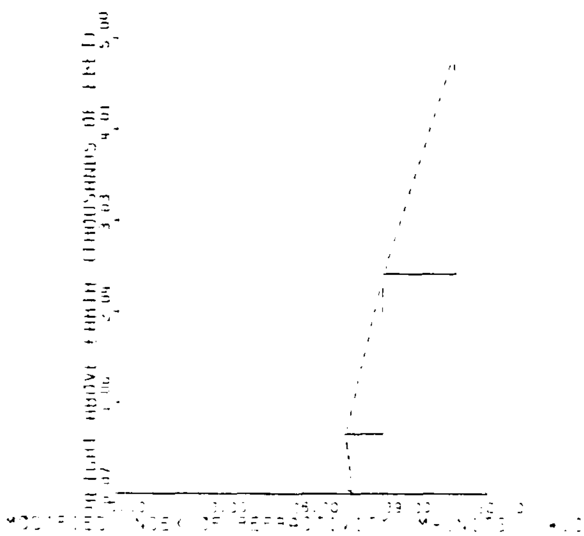


Figure 37: 'Modified Refractivity Profile - 24 May 80 0000Z'

Figure 38:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA 24 MAY 80, 0000Z

H0 = 90 FT RAY ANGLES: 0.5 TO 0.5 DEGREE FRQ: 2900 MHZ

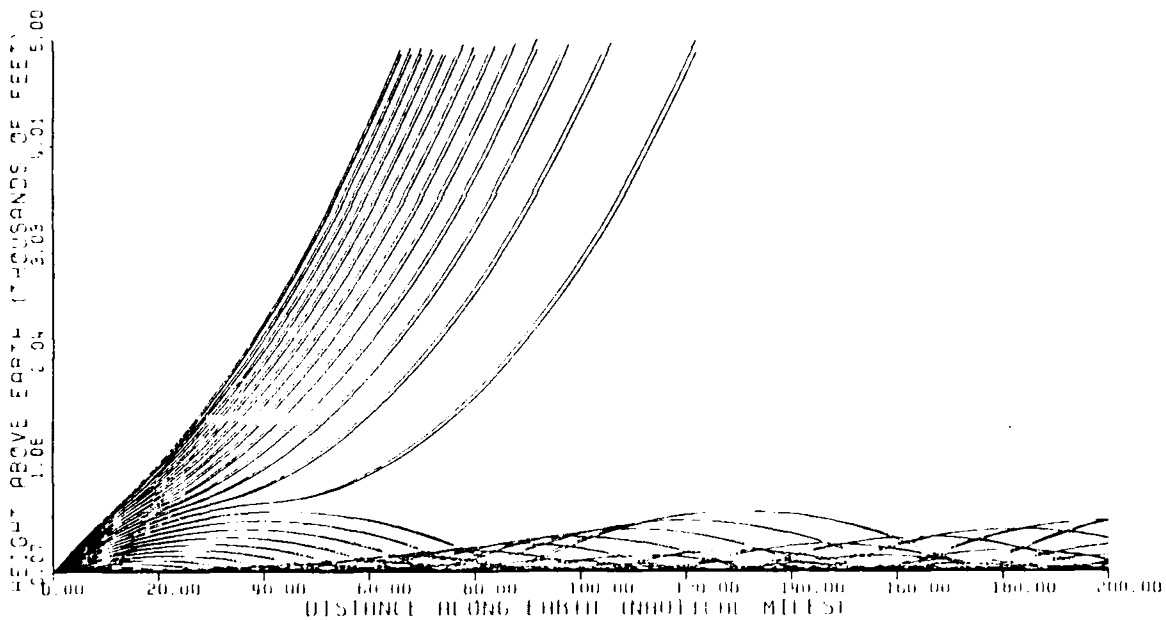
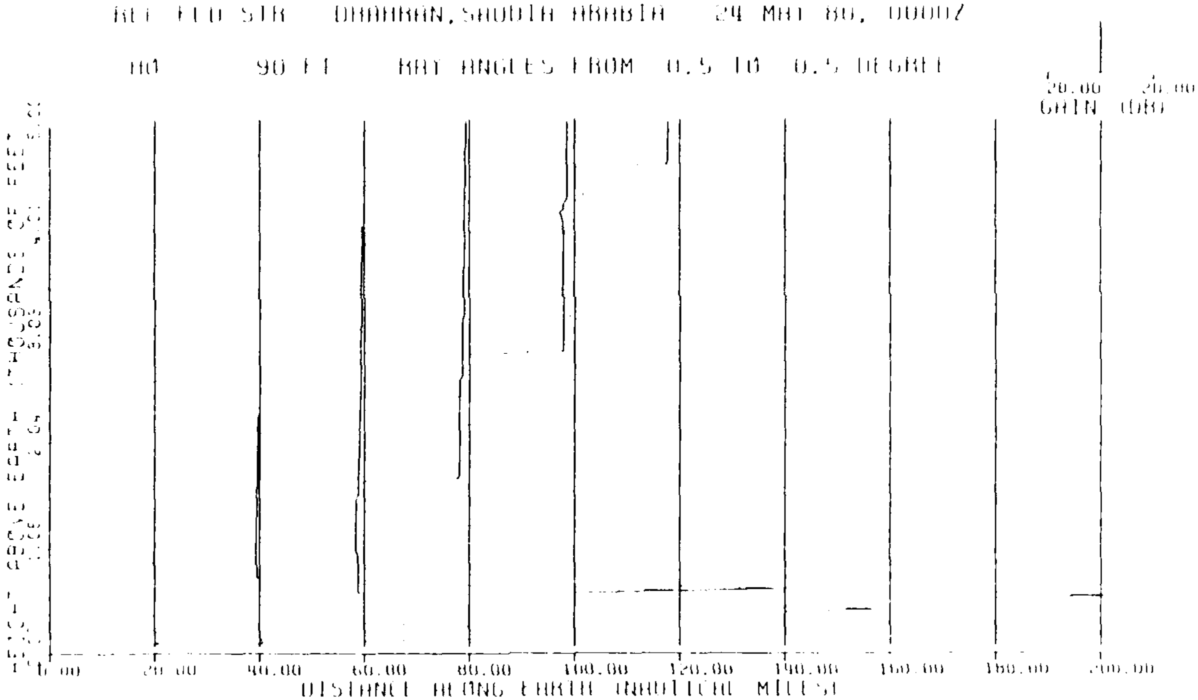


Figure 39:

REL FLD STR   DHAHRAN,SAUDIA ARABIA   24 MAY 80, 0000Z

H0   90 FT   RAY ANGLES FROM 0.5 TO 0.5 DEGREE



Set 3 is pictorially represented by 28 May 78 1200Z in the following figures. The height of the surface based duct averaged approximately 214 feet. The width of the duct was approximately 6 M-units. North winds at the 75-400 feet level, North and Northwest winds at the 3000-4000 feet level, and Northwest winds at the 4000-5250 feet level were dominant. The minimum trapped frequency for this set was 684.0 MHz. This occurred 18% of the time compared to the 2% of Figure 28.

Figure 42 shows that ray trapping occurs mainly between the earth's surface and 200 feet. The area above the duct shows the presence of a radar hole extending from 30 to 200 nautical miles.

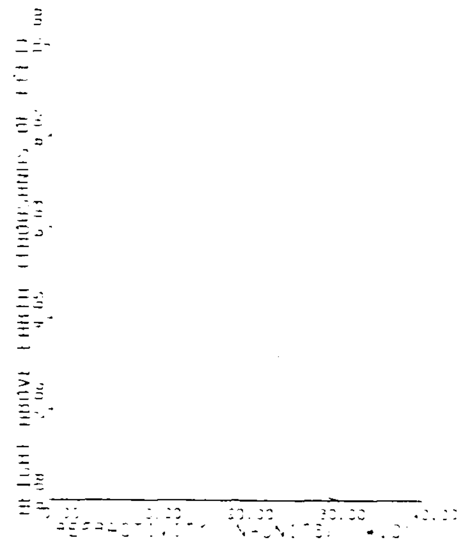


Figure 40: 'Atmospheric Refractivity Profile - 28 May 78 1200Z'

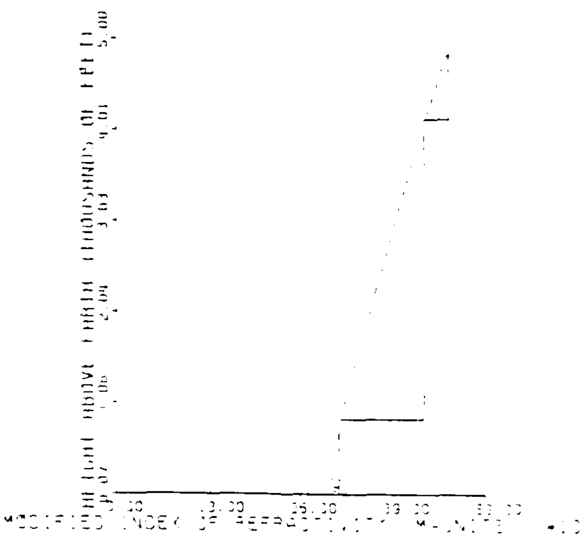
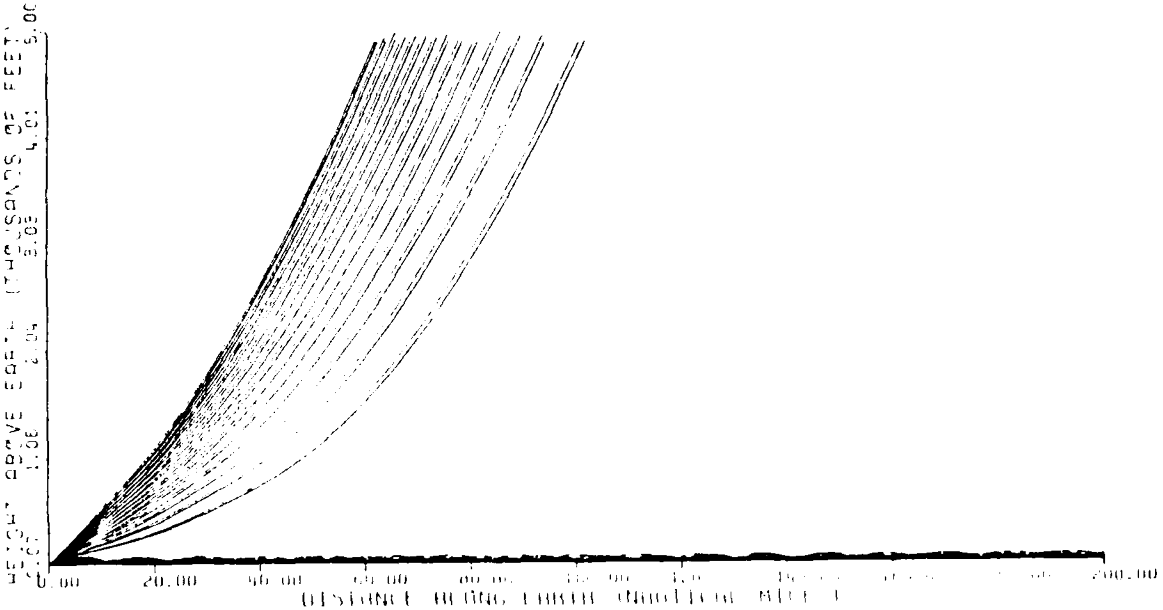


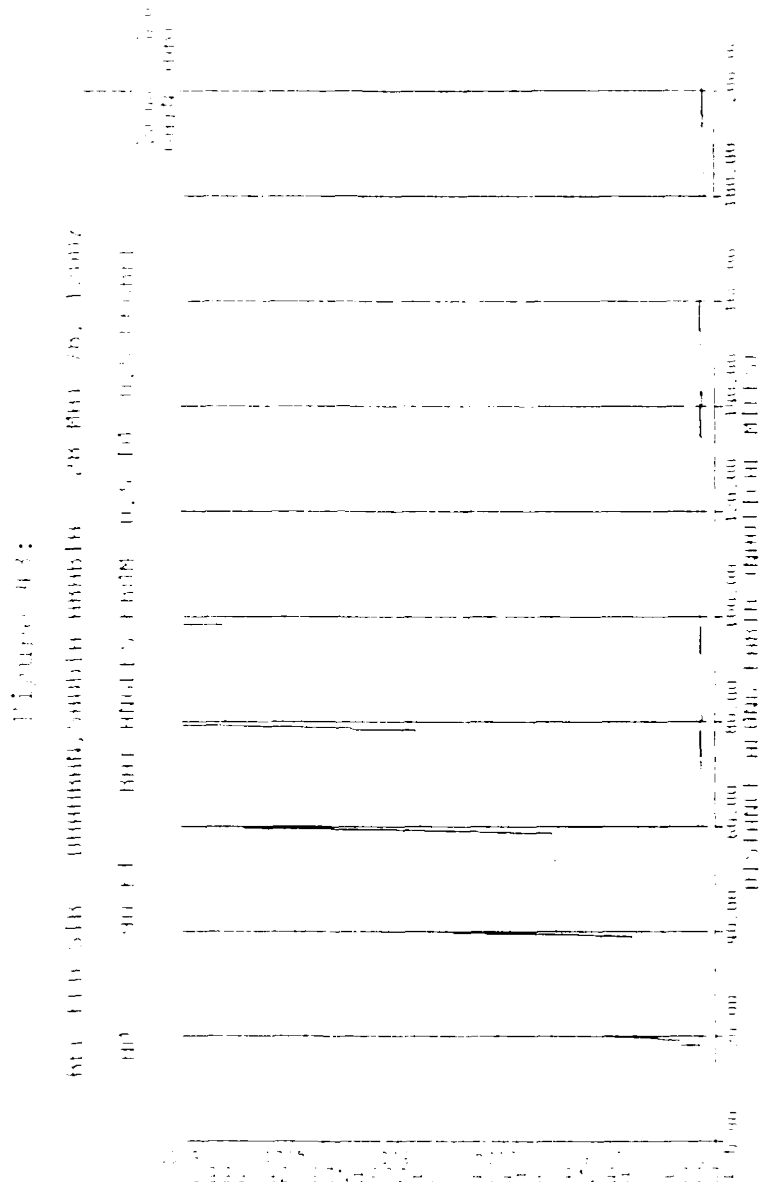
Figure 41: 'Modified Refractivity Profile - 28 May 78 1200Z'

Figure 42:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA 28 MAY 78, 1200Z

HO - 90 FT RAY ANGLES: 0.5 TO 0.[illegible] DEGREE FRQ: 2900 MHZ





Set 4 is pictorially represented by 26 May 80 0000Z in the following figures. The height of the surface based duct averaged approximately 1270 feet. The elevated layer was approximately 1093 feet thick. The width of the duct was approximately 49 M-units. There were too few data recordings to determine a dominant wind direction at the 75-400 feet, 3000-4000 feet and 4000-5250 feet levels. The minimum trapped frequency for this set was 47.3 MHz. This occurred 2% of the time compared to the 11% of Figure 28.

Figure 46 shows that ray trapping occurs mainly between the earth's surface and 1300 feet. It also shows a number of regions where there is a distinct absence of rays, particularly the area above the duct and the very low altitude hole extending from 30 to 50 nautical miles within the duct.

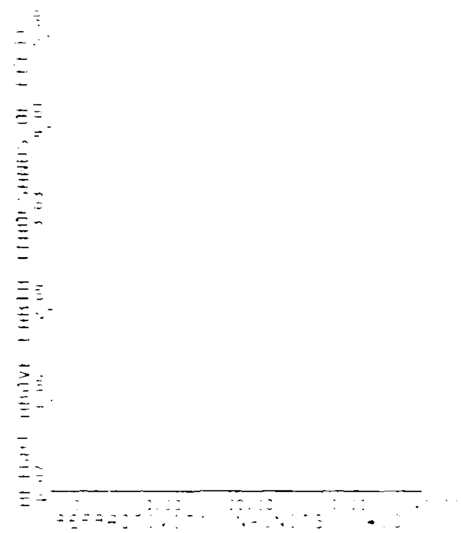


Figure 44: 'Atmospheric Refractivity Profile - 26 May 80 0000Z'

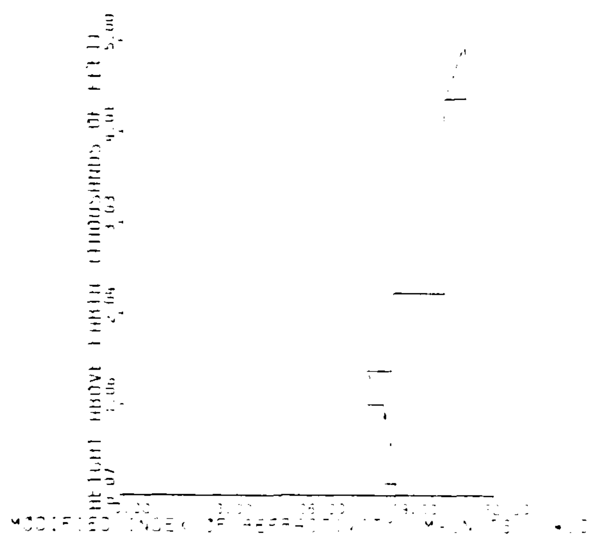
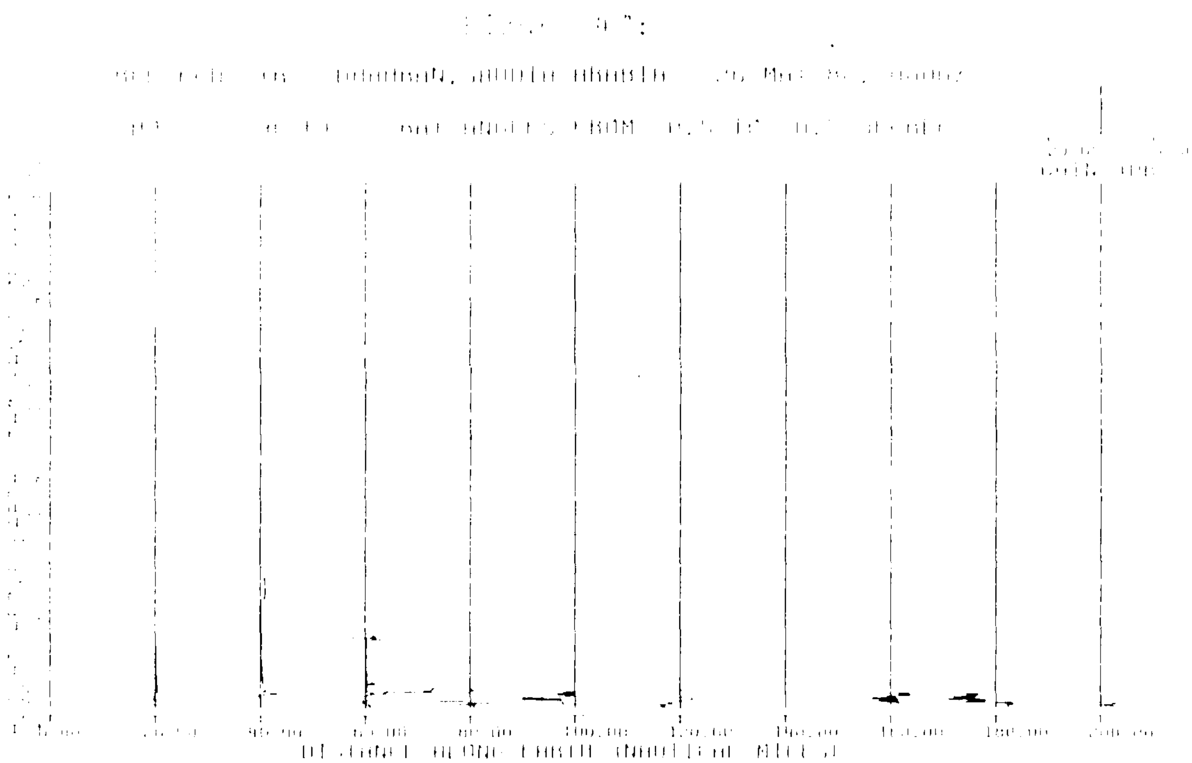


Figure 45: 'Modified Refractivity Profile - 26 May 80 0000Z'

Figure 9b:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA 26 MAY 86, 0000Z

HO - 90 FT RAY ANGLES: 0.5 TO 0.5 DEGREE FRQ: 2900 MHZ



Set 5 is pictorially represented by ... following figures. The height of the surface ... eraged approximately 640 feet. The elevated ... proximately 531 feet thick. The width of the ... proximately 11 M-units. There were too few ... to determine a dominant wind direction at the ... 3000-4000 feet and 4000-5250 feet levels. ... trapped frequency for this set was 132.3 MHz. ... 2% of the time compared to the 15% of Figure ...

Figure 50 shows ray trapping occurring ... earth's surface and 900 feet. There is an ... above the duct (radar hole) extending from 70 to ... cal miles and, a low altitude hole extending from ... nautical miles. The hole represents the region beyond the earth's horizon where rays are unable to penetrate and is frequently referred to as the earth's shadow region.

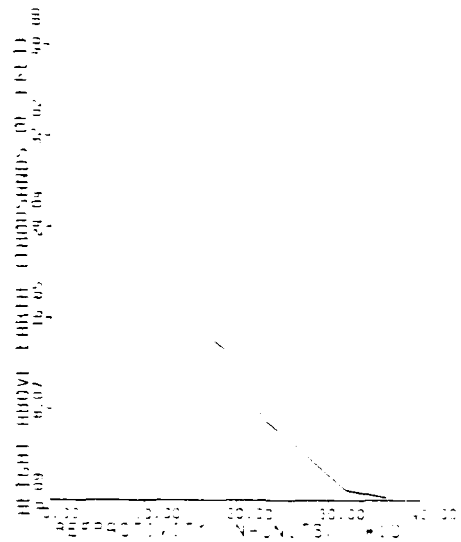


Figure 48: 'Atmospheric Refractivity Profile - 2 May 78 0000Z'

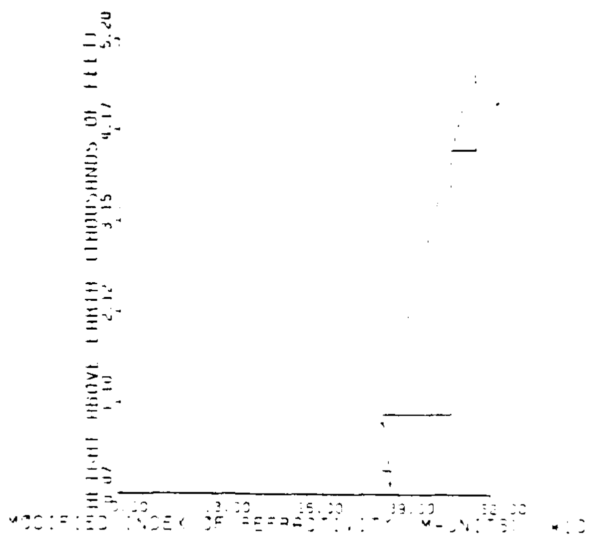


Figure 49: 'Modified Refractivity Profile - 2 May 78 0000Z'

Figure 50:

RAY TRACE FOR DAHRAN, SAUDI ARABIA 2 MAY 78, 0000Z

H0 - 90 FT RAY ANGLES: 0.5 TO 0.5 DEGREE FRQ: 2900 MHZ

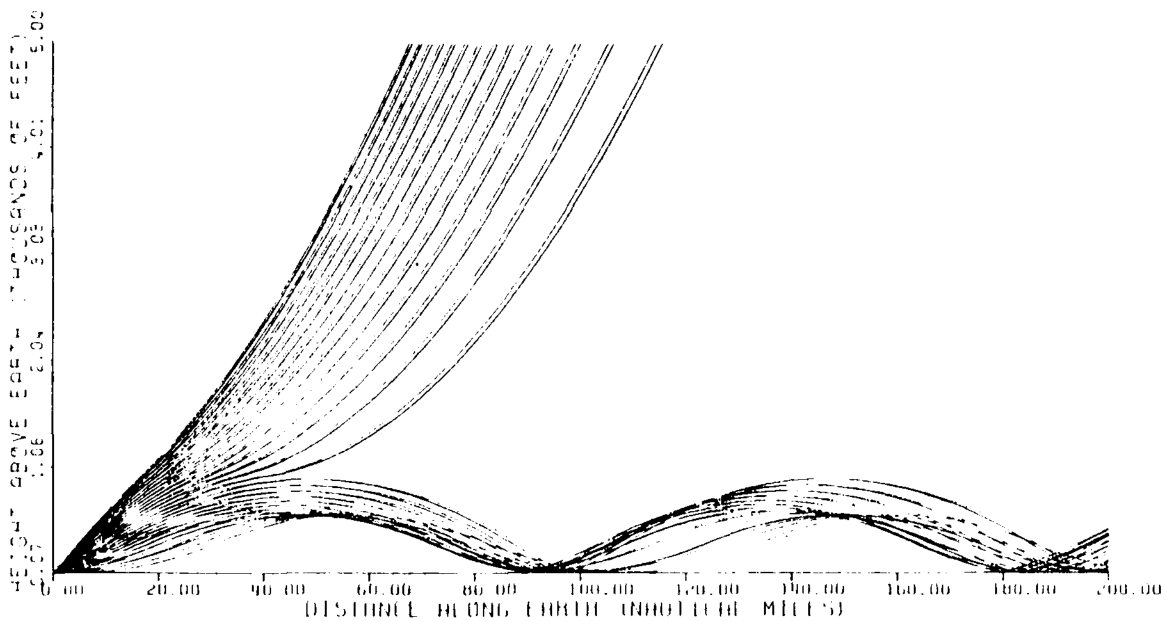
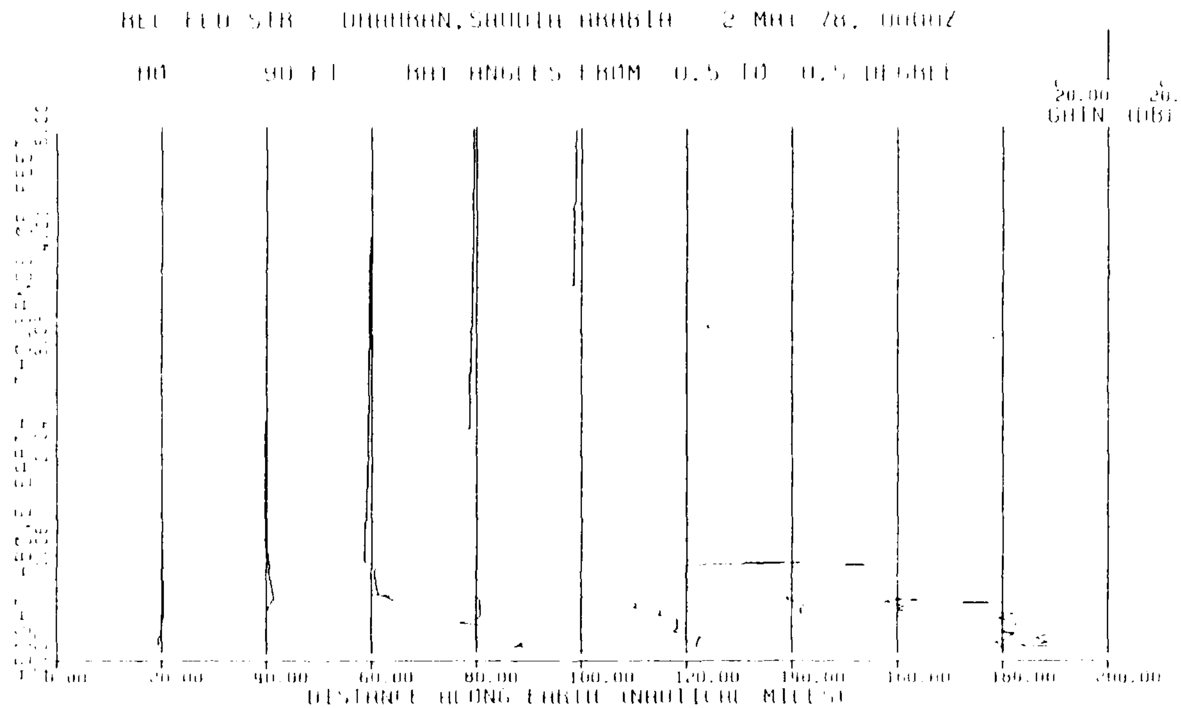


Figure 51:


REL FLD STR DHAHRAN,SAUDI ARABIA 2 MAR 78, 0000Z
HA 90 FT RAY ANGLES FROM 0.5 TO 0.5 DEGREE
20.00 20.00
GAIN (DB)
0.00 20.00 40.00 60.00 80.00 100.00 120.00 140.00 160.00 180.00 200.00
DISTANCE ALONG EARTH (NAUTICAL MILES)

Set 6 is pictorially represented by 17 Oct 79 0000Z in the following figures. The height of the surface based duct averaged approximately 1300 feet. The elevated layer was approximately 879 feet thick. The width of the duct was approximately 26 M-units. West winds at the 75-400 feet level, North winds at the 3000-4000 feet level, and North and Northwest winds at the 4000-5250 feet level were dominant. The minimum trapped frequency for this set was 45.7 MHz. This occurred 13% of the time compared to the 11% of Figure 28.

Figure 54 shows ray trapping occurring between the earth's surface and 1100 feet. There is an absence of rays above the duct (radar hole) extending from 60 to 200 nautical miles and, a low altitude hole extending from 30 to 80 nautical miles.

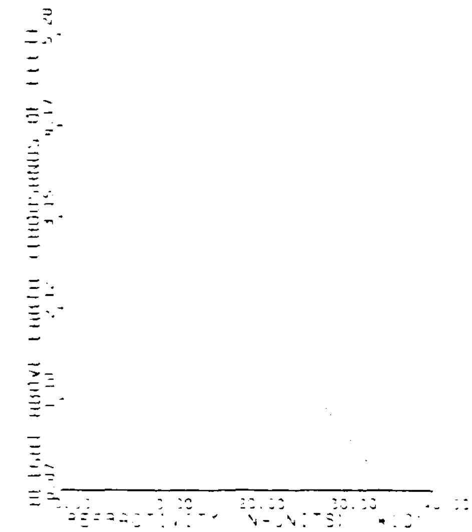


Figure 52: 'Atmospheric Refractivity Profile - 17 Oct 79 0000Z'

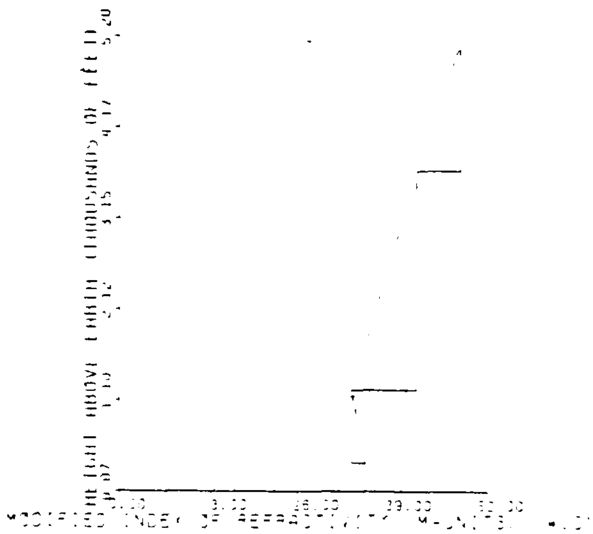


Figure 53: 'Modified Refractivity Profile - 17 Oct 79 0000Z'

Figure 54:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA 17 OCT 79, 0000Z

HØ = 90 FT RAY ANGLES: 0.5 TO 0.5 DEGREE FRQ: 2900 MHZ

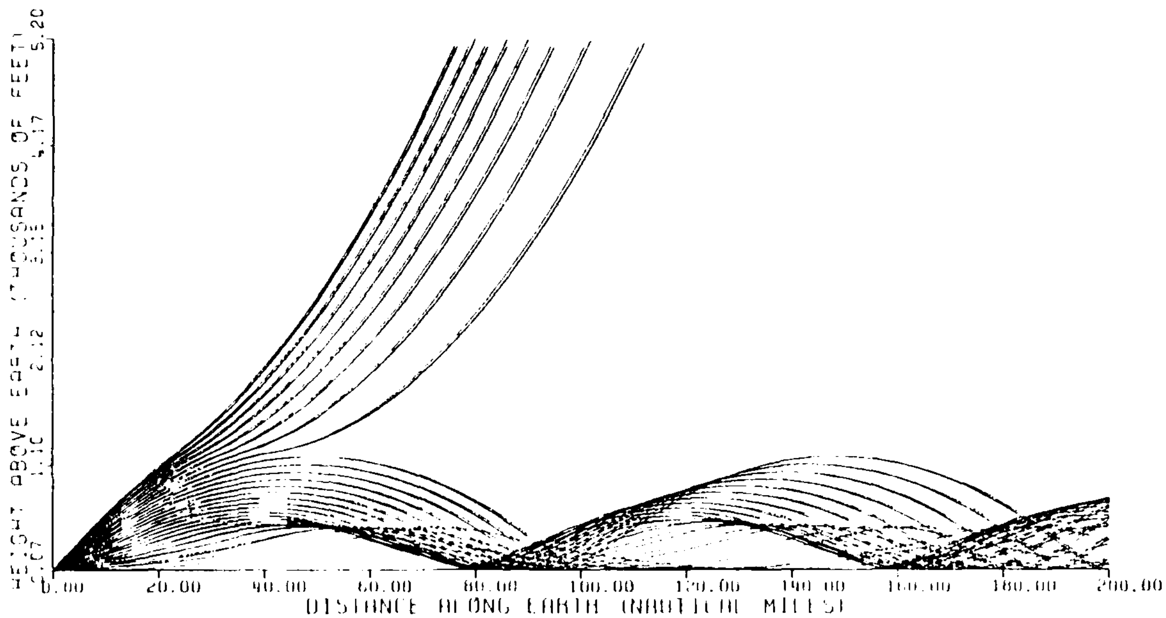
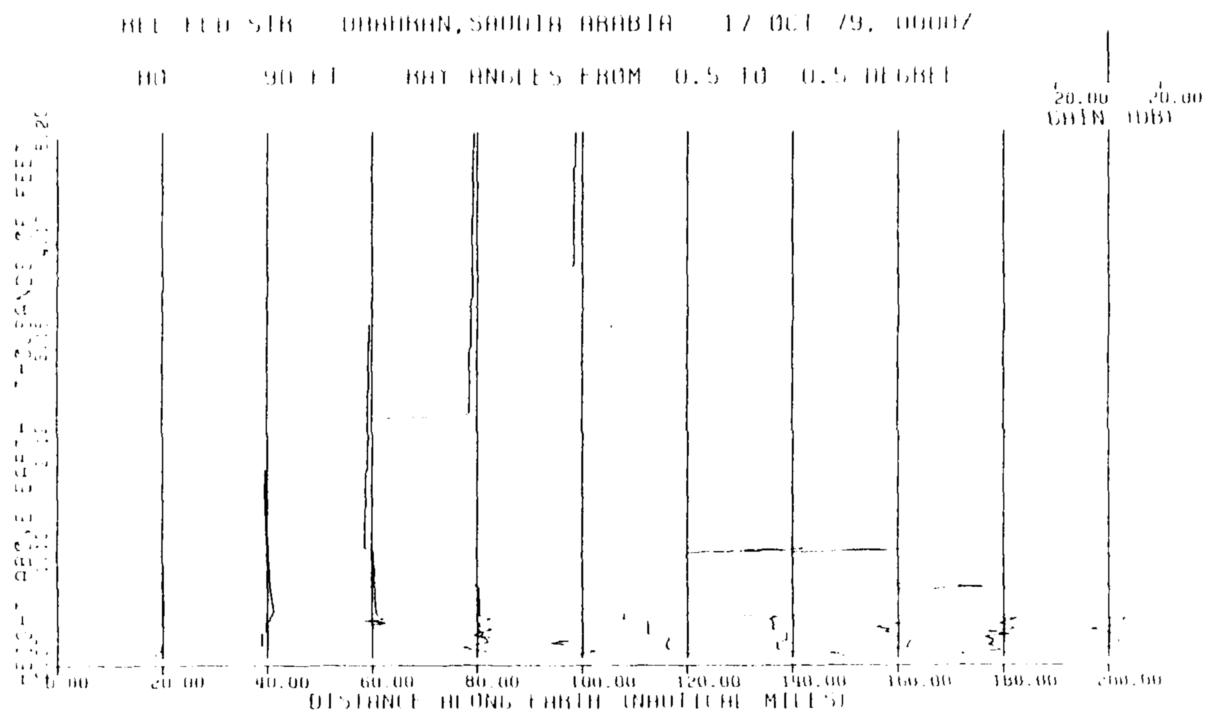


Figure 55:


DHAHRAN,SAUDIA ARABIA 17 OCT 79,
RAY ANGLES FROM 0.5 TO 0.5 DEGREE
20.00 20.00
GAIN (DB)
0.00 20.00 40.00 60.00 80.00 100.00 120.00 140.00 160.00 180.00 200.00
DISTANCE ALONG EARTH (NAUTICAL MILES)

Set 7 is pictorially represented by 25 May 80 0000Z in the following figures. The elevated duct averaged approximately 1289 feet in thickness. The elevated layer was approximately 755 feet thick. The width of the duct was approximately 20 M-units. There were too few data recordings to determine a dominant wind direction at the 75-400 feet, 3000-4000 feet and 4000-5250 feet levels.

Figure 58 shows the presence of an elevated duct. A low altitude (1000 feet) radar hole is present below the duct from 50 to 200 nautical miles.

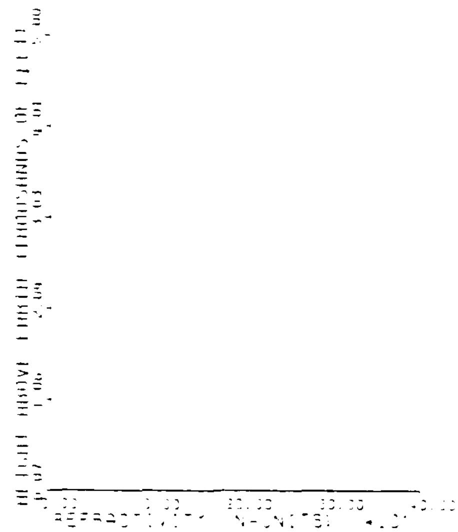


Figure 56: 'Atmospheric Refractivity Profile - 25 May 80 0000Z'

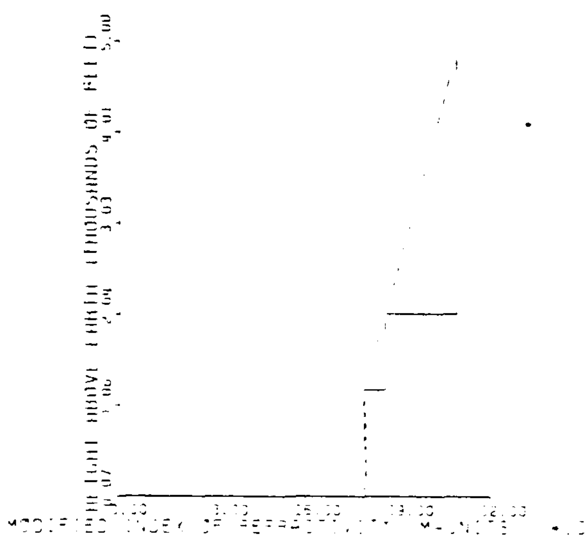


Figure 57: 'Modified Refractivity Profile - 25 May 80 0000Z'

Figure [illegible]:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA 25 MAY 80, 0000Z

H0 = 90 FT RAY ANGLES: 0.5 TO 0.5 DEGREE FRQ: 2900 MHZ

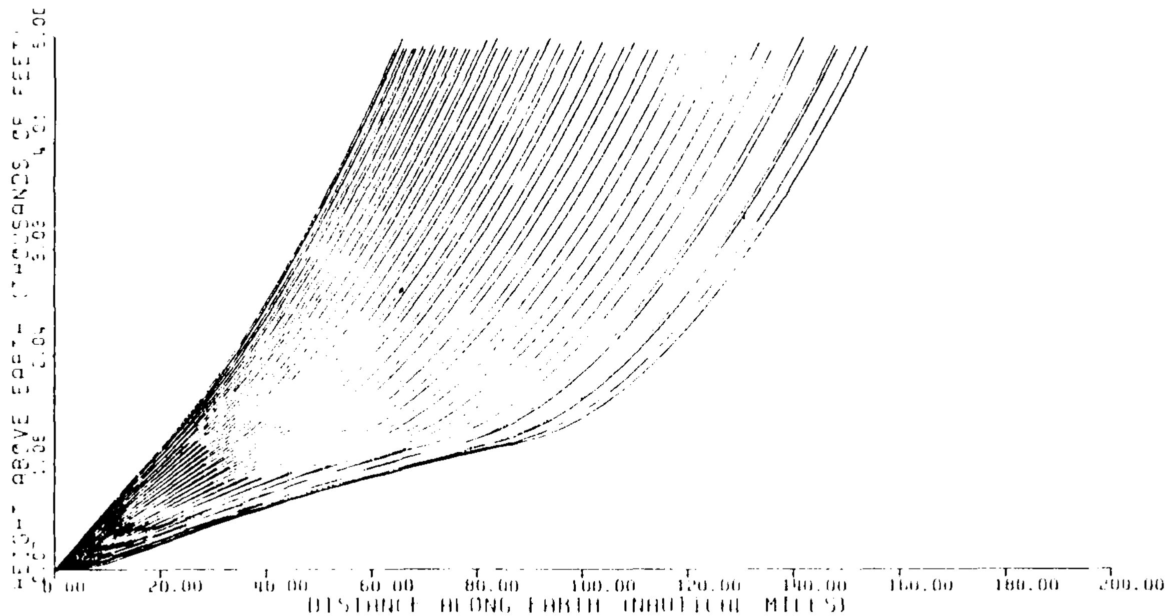
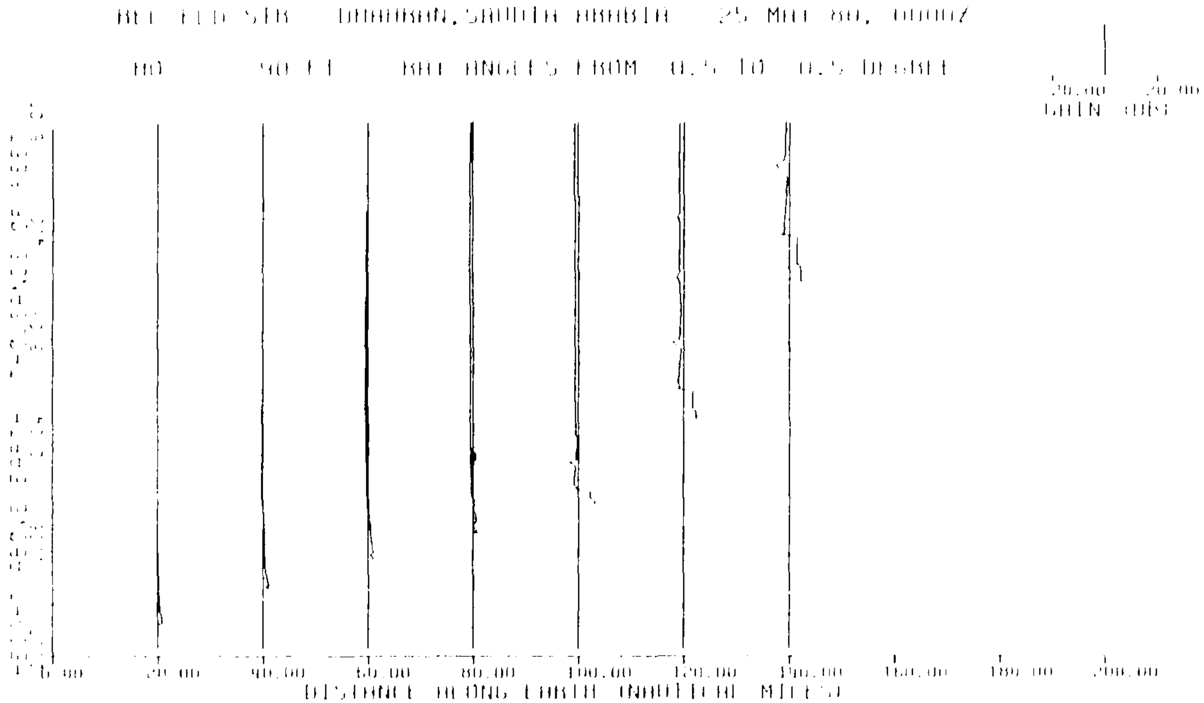


Figure 59:


REL FLD STR DHAHRAN, SAUDI ARABIA 25 MAR 80, 0000Z
HO 90 FT RAY ANGLES FROM 0.5 TO 0.5 DEGREE
GAIN (DB)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
DISTANCE ALONG EARTH (NAUTICAL MILES)

Set 8 is pictorially represented by 8 Oct 79 1200Z in the following figures. The elevated duct averaged approximately 850 feet in thickness. The elevated layer was approximately 666 feet thick. The width of the duct was approximately 13 M-units. North and East winds at the 75-400 feet level, North winds at the 3000-4000 feet level, and North and Northwest winds at the 4000-5250 feet level were dominant.

Figure 62 shows the presence of an elevated duct. A low altitude (2000 feet) radar hole is present below the duct from 50 to 200 nautical miles.

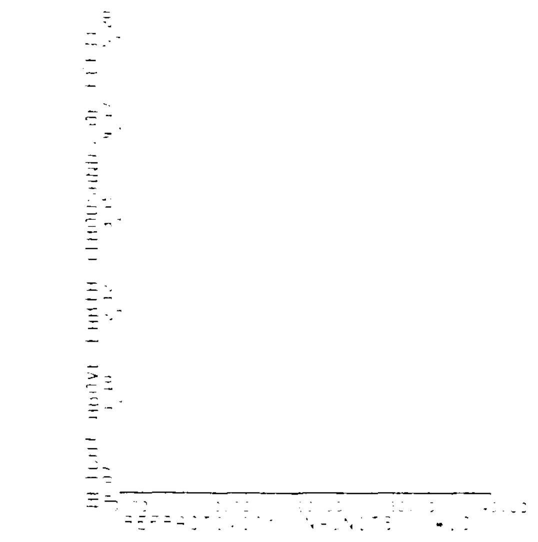


Figure 60: 'Atmospheric Refractivity Profile - 8 Oct 79 1200Z'

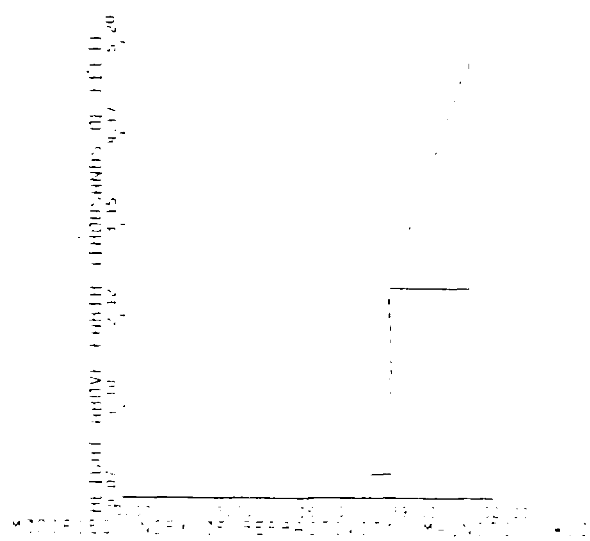


Figure 61: 'Modified Refractivity Profile - 8 Oct 79 1200Z'

Figure 62:

RAY TRACE FOR DHAHRAN, SAUDI ARABIA   8 OCT 79, 1200Z

HO = 90 FT   RAY ANGLES: 0.5 TO 0.5 DEGREE   FRQ: 2900 MHZ

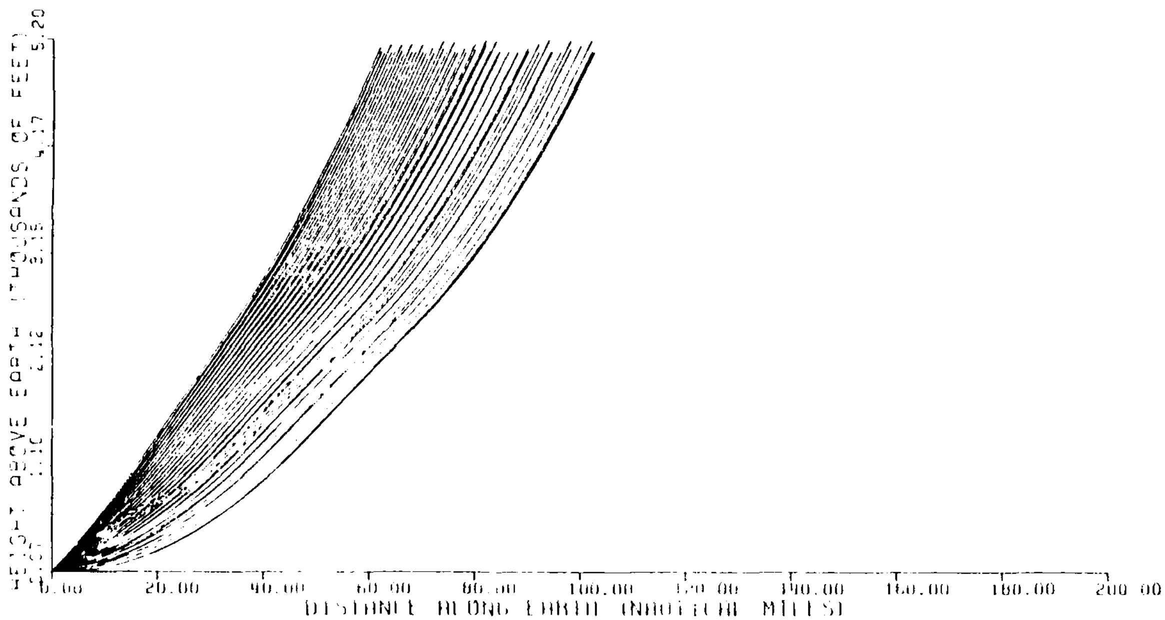
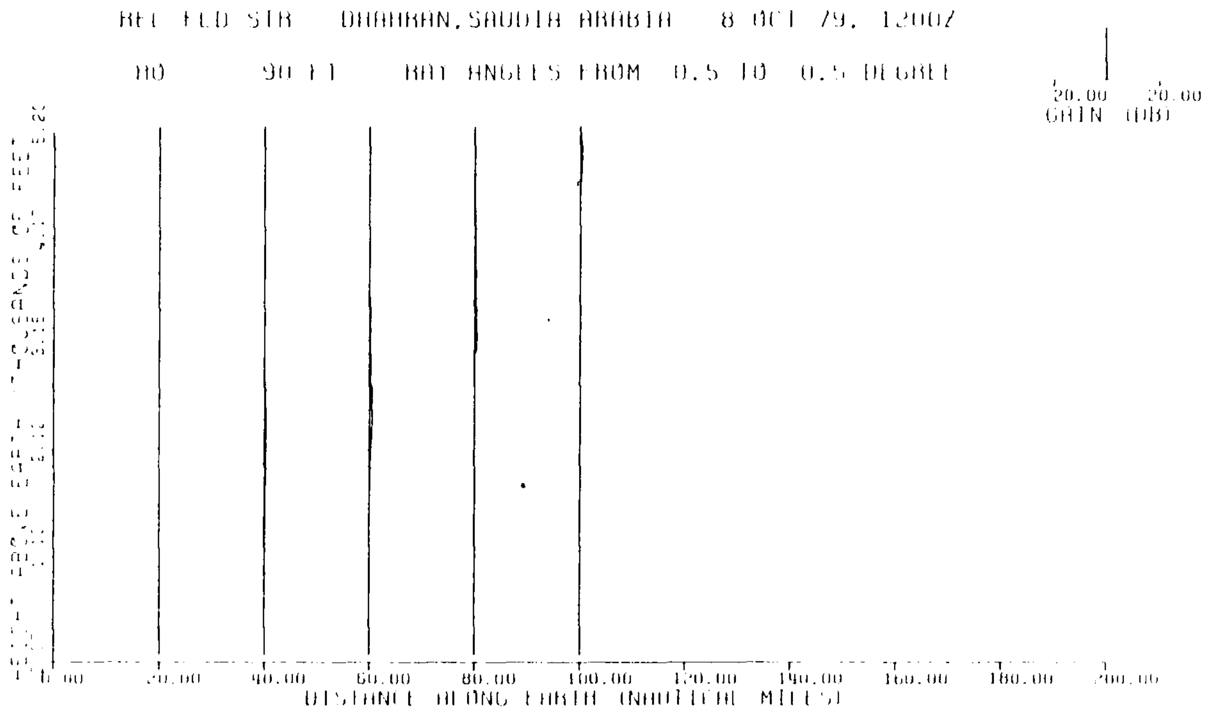


Figure 63:


REL FLD STR   DHAHRAN, SAUDIA ARABIA   8 OCT 79, 1200Z
HO   90 FT   RAY ANGLES FROM 0.5 TO 0.5 DEGREE
20.00   20.00
GAIN (DB)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
DISTANCE ALONG EARTH (NAUTICAL MILES)

Figures 64 thru 69 attempt to show the correlation of wind direction and wind speed to the establishment, location and heights of ducts. Unfortunately, wind direction and wind speed data were very limited between 400 feet and 3000 feet. No distinctive pattern was able to be obtained from the results. To compare the wind speeds depicted here with Figure 20 multiply meters per second by two to get knots (1 m/s = 1.945 knots).

Duct Type	Set	N	NE	E	SE	S	SW	W	NW	Calm	Total
Surface Based	1	2	0	0	3	2	2	2	2	3	16
Duct Caused by	2	8	2	5	2	1	2	10	4	7	41
Surface Layer	3	18	2	15	5	1	0	9	5	3	58
	Tot	28	4	20	10	4	4	21	11	13	115
Surface Based	4	1	0	0	0	0	1	1	1	2	6
Duct Caused by	5	2	0	1	1	0	0	1	0	0	5
Elevated Layer	6	3	2	3	2	2	5	14	3	10	44
	Tot	6	2	4	3	2	6	16	4	12	55
Elevated	7	3	1	3	0	0	0	3	0	0	10
Duct	8	6	2	5	0	0	0	4	2	2	21
	Tot	9	3	8	0	0	0	7	2	2	31
No Duct	Tot	45	15	17	11	0	5	24	4	7	128
TOTAL		88	24	49	24	6	15	68	21	34	329

Figure 64: 'Number of Occurrences of Wind Direction at Altitude 75-400 ft'

Duct Type	Set	N	NE	E	SE	S	SW	W	NW	Calm	Total
Surface Based	1	3	0	0	0	1	2	1	0	0	7
Duct Caused by	2	9	2	1	1	3	1	2	7	0	26
Surface Layer	3	13	3	1	1	1	4	4	14	0	41
	Tot	25	5	2	2	5	7	7	21	0	74
Surface Based	4	2	0	1	0	0	1	0	0	1	5
Duct Caused by	5	1	0	0	0	1	0	0	1	0	3
Elevated Layer	6	8	5	0	1	2	4	3	6	2	31
	Tot	11	5	1	1	3	5	3	7	3	39
Elevated	7	0	0	1	0	1	2	1	2	0	7
Duct	8	11	0	4	1	0	0	2	1	0	19
	Tot	11	0	5	1	1	2	3	3	0	26
No Duct	Tot	29	1	0	2	6	7	8	34	0	87
TOTAL		76	11	8	6	15	21	21	65	3	226

Figure 65: 'Number of Occurrences of Wind Direction at Altitude 3000-4000 ft'

Duct Type	Set	N	NE	E	SE	S	SW	W	NW	Calm	Total
Surface Based	1	1	2	0	0	3	3	1	5	0	15
Duct Caused by	2	11	2	1	2	3	2	7	15	0	43
Surface Layer	3	11	3	0	1	3	10	5	24	0	57
	Tot	23	7	1	3	9	15	13	44	0	115
Surface Based	4	2	0	1	0	0	1	1	1	0	6
Duct Caused by	5	1	0	0	0	2	0	1	1	0	5
Elevated Layer	6	9	5	4	2	4	6	5	10	0	45
	Tot	12	5	5	2	6	7	7	12	0	56
Elevated	7	1	0	0	1	0	1	2	3	1	9
Duct	8	7	1	4	2	0	1	3	5	0	23
	Tot	8	1	4	3	0	2	5	8	1	32
No Duct	Tot	34	4	1	1	8	14	15	44	1	122
TOTAL		77	17	11	9	23	38	40	108	2	325

Figure 66: 'Number of Occurrences of Wind Direction at Altitude 4003-5250 ft'

Wind Direction	Surface Based Duct Caused by Surface Layer 1	2	3	Surface Based Duct Caused by Elevated Layer 4	5	6	Elevated Duct 7	8
N	4.6	6.0	7.3	2.0	5.1	5.4	6.1	5.0
NE	0	5.1	4.1	0	0	5.1	2.5	5.1
E	0	5.6	4.3	0	2.0	4.4	5.6	4.1
SE	2.9	4.9	3.3	0	0	2.5	0	0
S	0	1.5	2.5	0	2.5	2.5	0	0
SW	1.8	2.5	0	2.0	0	1.7	0	0
W	2.8	3.1	3.3	1.5	3.6	2.6	2.0	4.1
NW	2.3	3.0	3.2	3.0	0	5.1	0	6.7

Figure 67: 'Average Wind Speed at Altitude 75 - 400 ft'

Wind Direction	Surface Based Duct Caused by Surface Layer 1	2	3	Surface Based Duct Caused by Elevated Layer 4	5	6	Elevated Duct 7	8
N	6.0	7.7	6.4	6.2	9.7	7.7	0	7.0
NE	0	4.6	2.7	0	0	3.9	0	0
E	0	4.1	3.0	4.1	0	0	0.5	4.0
SE	0	3.0	3.0	0	0	2.5	0	0.5
S	8.2	3.9	2.0	0	11.3	5.1	8.7	0
SW	1.5	2.0	6.0	4.1	0	4.7	3.3	0
W	0.5	5.7	7.0	0	0	2.7	11.3	5.9
NW	0	11.6	9.7	0	10.8	6.7	7.0	5.1

Figure 68: 'Average Wind Speed at Altitude 3000 - 4000 ft'

Wind Direction	Surface Based Duct Caused by Surface Layer 1	2	3	Surface Based Duct Caused by Elevated Layer 4	5	6	Elevated Duct 7	8
N	4.6	7.9	7.7	5.9	6.7	6.8	3.6	6.0
NE	3.8	5.9	3.0	0	0	4.9	0	3.6
E	7.2	2.5	0	7.2	0	2.4	0	7.3
SE	0	2.0	2.5	0	0	3.1	2.5	3.1
S	6.7	3.4	5.8	0	8.0	4.9	0	0
SW	2.7	6.9	6.0	4.6	0	4.8	6.7	5.6
W	5.6	5.8	6.9	1.5	4.1	5.1	8.2	4.8
NW	7.2	7.9	8.5	3.6	11.8	7.4	4.9	6.8

Figure 69: 'Average Wind Speed at Altitude 4003 - 5250 ft'

Surface based ducts caused by a surface layer occurred 35% of the time; surface based ducts caused by an elevated layer occurred 16% of the time; elevated ducts occurred 10% of the time; and, no ducts were present 39% of the time. During May at 0000Z, surface based ducts caused by a surface layer were predominant occurring 52% of the time. Of this 52%, Group 2 occurred 58% of the time. During May at 1200Z, there were no signs of ducting 52% of the time. However surface based ducts caused by a surface layer did occur 37% of the time. Of this 37%, Group 3 was present 68% of the time. During October at 0000Z, surface based ducts caused by elevated layers occurred 38% of the time. Of this 38%, Group 6 occurred 85% of the time. During October at 1200Z, there was no sign of ducting 56% of the time. Again however, surface based ducts caused by a surface layer did occur 24% of the time of which 86% were Group 3.

C. LAND-SEA BREEZE

Thru analysis it appears that between the heights of 951-1200 meters is where the weather maps used in Chapter III get there readings for wind direction and speed in the Dhahran area. Figures 70, 71, and 72 contain the data recorded during the radiosonde launches. This information matches pretty well with Figures 18, 19 and 20.

Time	YR	N	NE	E	SE	S	SW	W	NW	Calm
0000Z / 0400D	78	32	0	0	5	5	11	0	47	0
	79	15	8	15	15	15	0	8	23	0
	80	26	4	0	0	7	7	7	44	4
1200Z / 1600D	78	29	7	0	0	7	14	7	29	7
	79	46	8	0	8	8	8	23	0	0
	80	43	0	0	0	9	4	9	35	0
	Ave	32	4	2	4	8	7	8	33	2

Figure 70: 'May 1978, 1979, & 1980 Wind Direction (%) at 3120 - 3937 feet'

Time	YR	N	NE	E	SE	S	SW	W	NW	Calm
0000Z / 0400D	78	33	17	8	0	0	17	17	8	0
	79	36	9	5	5	9	14	0	18	5
	80	38	4	8	0	0	12	8	27	4
1200Z / 1600D	78	0	22	22	11	11	11	0	22	0
	79	48	0	0	0	5	14	10	24	0
	80	30	0	4	4	7	0	15	41	0
	Ave	34	6	6	3	5	10	9	26	2

Figure 71: 'October 1978, 1979, & 1980 Wind Direction (%) at 3120 - 3937 feet'

Month	N	NE	E	SE	S	SW	W	NW
May	8.1	4.1	3.6	2.8	6.1	4.6	6.7	9.3
October	6.8	3.4	3.1	3.2	5.3	5.0	4.4	7.1

Figure 72: 'May and October 1978, 1979, & 1980 Wind Speed (m/sec) Averages at 3120 - 3937 feet'

However, this data does not show the effect of the land-sea breeze. Data between the heights of 23 to 122 meters (75-400 feet) shows a better picture (See Figures 41, 42 & 43).

Time	YR	N	NE	E	SE	S	SW	W	NW	Calm
0000Z / 0400D	78	26	0	4	4	0	4	30	9	22
	79	24	4	0	8	8	8	16	0	32
	80	22	0	0	0	4	4	56	15	0
	Ave	24	1	1	4	4	5	35	8	17
1200Z / 1600D	78	57	13	26	4	0	0	0	0	0
	79	22	9	61	9	0	0	0	0	0
	80	54	19	19	8	0	0	0	0	0
	Ave	44	14	35	7	0	0	0	0	0

Figure 73: 'May 1978, 1979, & 1980 Wind Direction (%) at 75 - 400 feet'

Time	YR	N	NE	E	SE	S	SW	W	NW	Calm
0000Z / 0400D	78	4	0	4	7	0	14	46	4	21
	79	8	0	4	12	4	4	20	16	32
	80	4	0	0	4	0	4	64	7	18
	Ave	5	0	2	7	1	7	44	10	24
1200Z / 1600D	78	29	13	29	13	4	0	4	4	4
	79	33	21	29	4	4	4	0	4	0
	80	38	17	14	14	0	3	3	7	3
	Ave	34	17	23	10	3	3	3	5	3

Figure 74: 'October 1978, 1979, & 1980 Wind Direction (%) at 75 - 400 feet'

Month	Time	N	NE	E	SE	S	SW	W	NW
May	0000Z	5.3	4.6	2.0	2.2	2.2	2.8	2.8	3.5
	1200Z	8.1	5.5	4.8	5.2	0	0	0	0
October	0000Z	3.8	0	2.0	2.7	2.5	2.2	2.7	3.8
	1200Z	6.9	5.4	3.6	3.6	3.2	3.6	5.7	4.6

Figure 75: 'May and October 1978, 1979, & 1980 Wind Speed (m/sec) Averages at 75 - 400 feet'

At 0000Z winds from the west at 2.7 meters per second (5.4 knots) form the land breeze. At 1200Z winds from the north at 7 to 8 meters per section or from the east at 4 meters per second (8 knots) form the sea breeze. When the winds blow from the west, northwest or southwest forming the land breeze, they shifted to the north, northeast or east by 1200Z to form the sea breeze. Wind speed was stronger for the sea breeze as expected. No correlation could be determined between the occurrence of land-sea breezes and ducting.

V. TACTICAL APPLICATIONS

Tactical military commanders can not survive without making use of and exploiting the EM spectrum. Although the EM spectrum has been utilized the military has not fully considered atmospheric effects on the EM spectrum. The following commonly used systems exemplify the affects atmospheric anomalies have on EM propagation.

A. RADAR

The military has been the major user of radar and the contributor of its developmental cost. The major areas of radar application for the military includes but is not limited to air traffic control, aircraft navigation, ship safety, remote sensing (i.e. used as a remote sensor of the weather or as an ionospheric sounder), surveillance and for control and guidance of weapons. Conventional radars generally operate between 220 MHz and 35 GHz. These are not the limits. Radars which operate outside these limits include skywave HF over-the-horizon radars (operating as low as 4 MHz), ground wave HF radars (operating as low as 2 MHz), millimeter radars (94 GHz) and laser radars operating at yet higher frequencies [Ref. 40]. Some examples of radars presently utilized by the U.S. Military are as follows:[Ref. 41]

Nomenclature	Use	Operating Frequency
AN/FPS-6	Heightfinding	2700 - 2900 MHz
AN/PPS-5	Combat Surveillance	16 - 16.5 GHz
AN/PPS-6	Battlefield Surveillance	9 - 9.5 GHz
AN/TPN-18A	Ground Control Approach	9 - 9.6 GHz
AN/TPN-25	Precision Approach	9 - 9.2 GHz
AN/TPS-32	Long Range Surveillance	2905 - 3080 MHz
AN/TPS-43E	Air Defense	2900 - 3100 MHz
AN/VPS-2	Air Defense	9200 - 9250 MHz

The radar equation relates the range of a radar to the characteristics of the transmitter, receiver, antenna, target and environment.

$$R_{max} = \left[\frac{P_r \; G_r \; A_e \; \sigma \; I_i(n)}{(4\pi)^2 \; K \; (T_a + T_e) \; B_n \; L_s \; (S/N)_{min}} \right]^{1/4} \qquad \text{(Eqn 10)}$$

where,

R_{max} = maximum radar range (m).

P_r = peak power output of radar (watts).

G_r = antenna gain of radar.

A_e = effective antenna area (m^2).

σ = radar cross section (m^2).

$I_i(n)$ = integration improvement factor.

K = Boltzmann's constant (1.38×10^{-23} J/Deg)

T_a = antenna noise temperature (°K).

T_e = equipment noise temperature (°K).

B_n = noise bandwidth (Hz).

L_s = system losses.

$(S/N)_{min}$ = minimum signal to noise ratio of a single pulse.

This equation finds the maximum radar range. However it does not take into consideration atmospheric refractivity which as seen in Figures 34, 38, 42, 46, 50, 54, 58 and 62 can have a severe impact on what a radar actually sees.

Battlefield surveillance radars such as the AN/PPS-5 which can detect men out to 5000 meters and vehicles out to 10,000 meters or the AN/PPS-6 which can detect personnel out to 1500 meters and vehicles out to 3000 meters look out horizontally along the earth's surface and therefore will not be affected by atmospheric refractivity. Aircraft control, precision approach (AN/TPN-25 & AN/TPN-18A) and short range air defense (AN/VPS-2) radars which look out to a range of 40 miles will be slightly affected. Atmospheric conditions were present 6.4% of the time which would cause EM waves to

bend (see Figures 34 & 46) creating a radar hole above the 2000 foot level. Long range surveillance (AN/TPS-32) and air defense (AN/TPS-43E) radars which have ranges in excess of 240 nautical miles (nmi) will be severely affected. Radar holes were present starting at a distance of 30 nmi from the radar at a height of 2000 feet 57% of the time under study.

B. COMMUNICATIONS

HF and VHF communication systems operating at frequencies less than 45.7 MHz would not have been appreciably affected by atmospheric refractivity during the study months. Transmitters operating above the following frequencies would have experienced extended ranges at the also listed percentages:

Frequency	Extended Range Percentage
45.7 MHz	13%
47.3 MHz	15%
51.8 MHz	20%
80.2 MHz	32%
132.3 MHz	34%
684.0 MHz	52%

The trapping of EM signals in surface ducts and elevated ducts also showed that signal strength loss was not as severe as it would have been had there been no duct present. Hence the intercept of signals could be made at longer distances and with less sensitive receivers.

VI. CONCLUSIONS AND RECOMMENDATIONS

Surface based ducts and elevated ducts were present 61% of the time during the months of May and October in 1978, 1979 and 1980. These ducts would most severely affect long range surveillance radars due to the presence of radar holes, and communication systems by extending their normal transmitting range. Radar holes were predominantly present starting at a distance of 80 nmi from the radar at a height of 2000 feet and rising. Elevated ducts present 10% of the time to a maximum height of 2000 feet will also degrade the performance of Side Looking Airborne Radar (SLAR) and Joint Army Air Force Surveillance and Attack Radar System (JSTARS) (aircraft height approximately 15,000 feet) if they were to be utilized in this area of the world.

The land-sea breeze phenomenon was present during the study months. No correlation could be determined between the occurrence of the land-sea breezes and ducting.

A portion of this thesis attempted to show the correlation of wind direction and wind speed to the establishment, location and heights of ducts. Wind direction and speed data was very limited between 400 feet and 3000 feet. By coincidence this area happened to be located either directly inside or just above the duct. Hence no distinctive pattern was able to be obtained from the results. In the future, more data is needed to be obtained from radiosonde launches in the predicted duct area in order for a more reasonable analysis to occur.

APPENDIX A

COMPUTER PROGRAM

```
//PETERSEN JOB  (2310,0391),'SMC 2310',CLASS=C                    ..
//*MAIN CEG=NPGVM1.2310P,LINES=(60)                                ..
//*FORMAT PR,DDNAME=PLOT.SYSVECTR,DEST=LOCAL                       ..
//  EXEC FRTXCLGP,PARM.FORT='MAP,GOSTMT,XREF'                      ..
//FORT.SYSIN DD *                                                  ..
C     THIS PROGRAM WAS ORIGINALLY DEVELOPED BY RAYMOND P. ..
C     WASKY.  PROGRAM CONVERTED FOR USE ON THE IBM 3033 BY..
C     JIM BLAKE.  PROGRAM MODIFIED FOR "M" AND "DM/DZ" BY ..
C     BY WAYNE F. PETERSEN.                                ..
C-----THIS PROGRAM IS A GEOMETRIC OPTICS MODEL OF WAVE    ..
C-----PROPAGATION THROUGH AN INHOMOGENEOUS ATMOSPHERE HAVING
C-----A VERTICALLY STRATIFIED INDEX OF REFRACTION.  THE   ..
C-----PROGRAM CALCULATES THE DIRECTION OF WAVEFRONT       ..
C-----PROPAGATION BY SOLVING THE EULER-LAGRANGE EQUATIONS OF
C-----RAYS NORMAL TO INCREMENTAL WAVEFRONT SURFACES.  THE ..
C-----RAY TRAJECTORIES ARE THEN USED TO COMPUTE THE RELATIVE
C-----EMITTER FIELD STRENGTH OR POWER DENSITY (NORMALIZED TO
C-----TO FREE SPACE)  AS A FUNCTION OF ALTITUDE AND DISTANCE
C-----ALONG THE EARTH'S SURFACE.  FIELDS WHICH ARE REFLECTED
C-----FROM THE EARTH ARE ATTENUATED  BY A FRESNEL REFLECTION
C-----COEFFICIENT AND A SURFACE ROUGHNESS FACTOR.  THE    ..
C-----ELEVATION ANGLE AND TIME OF PROPAGATION ARE CALCULATED
C-----ALONG EACH RAY PATH TO  DETERMINE THE DIRECTION OF THE
C-----WAVEFRONT PROPAGATION  VECTOR AND THE  PHASE RELATION-
C-----SHIP BETWEEN INTERFERING WAVEFRONTS FOR THE FIELD   ..
C-----STRENGTH AND POWER DENSITY COMPUTATIONS.            ..
C                                                          ..
```

```
C*************************************************************
C                         DATA INPUT                          *
C                        ------------                         *
C THIS PROGRAM WILL ACCEPT TWO TYPES OF DATA INPUT.  SET      *
C DATCTRL = 0 FOR INPUT OF HEIGHT AND REFRACTIVITY.  SET      *
C SET DATCTL = 1 FOR INPUT OF HEIGHT, N, M, DNDZ, & DMDZ.     *
C INPUT FORMAT IS 6(F10.3).  IF THE HIGHEST HEIGHT IN FEET    *
C IS LESS THAN YOUR ASSIGNED YMAX you can only request        *
C PROFILES AND PLOTS FOR "N", "DN/DZ", THE ray trace and      *
C POWER DENSITY.  SEE SUBROUTINE REFRCT FOR explanation       *
C                                                             *
C CHECK READ STATEMENTS FOR OTHER NECESSARY DATA TO BE        *
c input.                                                      *
C                                                             *
C*************************************************************
C                                                            ..
C*************************************************************
C                           PLOTS                             *
C                          -------                            *
C THERE ARE SIX PLOTS AVAILABLE IN THIS PROGRAM:              *
C     1. REFRACTIVITY (N-UNITS) VS HEIGHT (FEET)              *
C     2. DN/DZ (N-UNITS/KM)      VS HEIGHT (FEET)             *
C     3. MODIFIED INDEX OF REFRACTIVITY (M-UNITS)             *
c        vs Height (feet)                                     *
C     4. DM/DZ (M-UNITS/KM)      VS HEIGHT (FEET)             *
C     5. RAY TRACE                                            *
C     6. RELATIVE POWER DENSITY                               *
C                                                             *
C*************************************************************
C                                                            ..
C                                                            ..
```

```
C*************************************************************
C                    VARIABLE DEFINITIONS                    *
C                                                            *
C  NCASE         - NUMBER OF PROGRAM RUNS.                   *
C  NPRO          - CODE FOR REFRACTIVITY MODEL               *
C                  (=0 FREE SPACE MODEL;                     *
C                  =1 EXPONENTIAL MODEL; =2 INPUT MODEL)     *
C  NDATA         - NUMBER OF REFRACTIVITY PROFILE DATA       *
C                  LEVELS (NDATA = 1 IF NPRO = 0 OR 1)       *
C  HN(1)         - HIGHEST ALTITUDE IN REFRACTIVITY          *
C                  PROFILE (FEET)                            *
C  HN(NDATA)     - LOWEST ALTITUDE IN REFRACTIVITY           *
C                  PROFILE (FEET)                            *
C  HF(?)         - ALTITUDE IN REFRACTIVITY PROFILE          *
C                  (METERS)                                  *
C  RN(1)         - REFRACTIVITY AT HN(1)                     *
C  RN(NDATA)     - REFRACTIVITY AT HN(NDATA)                 *
C  AHS           - EARTH SURFACE ALTITUDE IN FEET ABOVE      *
C                -  SEA LEVEL                                *
C  AHO           - EMITTER ALTITUDE IN FEET ABOVE            *
C                -  SEA LEVEL                                *
C  YMIN          - MINIMUM ALTITUDE IN FEET ABOVE SEA        *
C                  LEVEL FOR PRINT AND PLOT OUTPUT           *
C  YMAX          - MAXIMUM ALTITUDE IN FEET ABOVE SEA        *
C                  LEVEL FOR PRINT AND PLOT OUTPUT           *
C  XDELTA        - DISTANCE INTERVAL IN NAUTICAL MILES       *
C                  FOR PRINT AND PLOT OUTPUT                 *
C  XFINAL        - MAXIMUM DISTANCE IN NAUTICAL MILES        *
C                  FOR PRINT AND PLOT OUTPUT                 *
C  ELOS1         - HIGHEST RAY ANGLE IN DEGREES              *
C  ELOS2         - LOWEST RAY ANGLE IN DEGREES               *
C                  (DIFFERENCE BETWEEN ELOS1 AND ELOS2       *
C                  CAN BE NO MORE THAN ONE DEGREE)           *
C  FRQ           - EMITTER FREQUENCY IN MEGAHERTZ            *
```

```
C   PW                - EMITTER PULSE WIDTH IN MICROSEC             *
C                       (IF EMITTER IS CONTINUOUS WAVE SET          *
C                       PW = 1000000.0 )                            *
C   NHV               - CODE FOR EMITTER POLARIZATION               *
C                       (=1 HORIZ; =2 VERT)                         *
C   NSL               - CODE FOR EARTH SURFACE TYPE                 *
C                       =1 SEA WATER; =2 VERY DRY LAND;             *
C                       =3 AVERAGE LAND; =4 VERY MOIST LAND)        *
C   NRMS              - CODE FOR SURFACE ROUGHNESS                  *
C                       (SEE TABLE BELOW)                           *
C          CODE       STANDARD DEVIATIONS OF HEIGHT                 *
C         (NRMS)        (SEA)        (LAND)                         *
C           0           0.0            0                            *
C           1           0.2            9                            *
C           2           0.6           30                            *
C           3           1.1           56                            *
C           4           1.7          112                            *
C           5           2.6          214                            *
C           6           4.3          429                            *
C           7           8.6         1288                            *
C           8          12.9         2146                            *
C   KREF              - CODE FOR REFRACTIVITY PROFILE PRINTOUT      *
C                       (=0 NO PRINTOUT; =1 PRINTOUT)               *
C   KGRAD             - CODE FOR REFRACTIVITY GRADIENT PROFILE      *
C                       PRINTOUT (=0 NO PRINTOUT; =1 PRINTOUT)      *
C   KRAY              - VARIABLE NOT USED - SET = 0                 *
C   KPLOT             - CODE FOR RELATIVE FIELD STRENGTH OR         *
C                       POWER DENSITY PRINTOUT                      *
C                       (=0 NO PRINTOUT;                            *
C                        =1 RELATIVE FIELD STRENGTH PRINTOUT;       *
C                        =2 RELATIVE POWER DENSITY PRINTOUT)        *
C   KMIR              - CODE FOR MODIFIED INDEX OF REFRACTIVITY     *
C                       PRINTOUT (=0 NO PRINTOUT; =1 PRINTOUT)      *
```

```
C   KMGRAD             - CODE FOR MOD INDEX OF REFRAC GRADIENT  *
C                        PRINTOUT (=0 NO PRINTOUT; =1 PRINTOUT) *
C   NREF               - CODE FOR REFRACTIVITY PLOT             *
C                       (=0 NO PLOT; =1 PLOT)                   *
C   NGRAD              - CODE FOR REFRACTIVITY GRADIENT PLOT    *
C                       (=0 NO PLOT; =1 PLOT)                   *
C   NRAY               - CODE FOR RAY TRACE PLOT                *
C                       (=0 NO PLOT; =1 PLOT)                   *
C   NPLOT              - CODE FOR RELATIVE FIELD STRENGTH OR    *
C                        POWER DENSITY PLOT                     *
C                        (=0 Nc plct;                           *
C                         =1 RELATIVE FIELD STRENGTH PRINTOUT;  *
C                         =2 RELATIVE POWER DENSITY PLOT)       *
C   NMIR               - CODE FOR MODIFIED INDEX OF REFRACTIVITY*
C                        PLOT (=0 NO PLOT; =1 PLOT)             *
C   NMGRAD             - CODE FOR MOD INDEX OF REFRAC GRADIENT  *
C                        PLOT (=0 NO PLOT; =1 PLOT)             *
C   SCALE              - SCALE FACTOR FOR ENLARGING OR REDUCING *
C                        PLOT SIZE FROM ITS NORMAL 5 X 10       *
C                        INCH FORMAT.  NORMAI PLOT SIZE GIVEN   *
C                        WITH SCALE = 1.0                       *
C   IAHD               - NUMBER OF CHARACTERS IN PLOT BANNER    *
C   AHD                - CHARACTERS IN PLOT BANNER              *
C   IXTL               - NUMBER OF CHARACTERS IN X-AXIS LABEL   *
C   XTL                - CHARACTERS IN X-AXIS LABEL             *
C   IYTL               - NUMBER OF CHARACTERS IN Y-AXIS LABEL   *
C   YTL                - CHARACTERS IN Y-AXIS LABEL             *
C   ITTL               - NUMBER OF CHARACTERS IN FIRST LINE OF  *
C                        PLOT TITLE                             *
C   TTL                - CHARACTERS IN FIRST LINE OF PLOT TITLE *
C   ITLE               - NUMBER OF CHARACTERS IN SECOND LINE OF *
C                        PLOT TITLE                             *
C   TLE                - CHARACTERS IN SECOND LINE OF PLOT TITLE*
C                                                               ..
```

```
C*****************************************************************
C
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /ONECOM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2
     1      ,RHO(51,30),PHI(51,30),PI,CMF,CNAUT,denot
     2      ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA
      COMMON /TWOCOM/ RA,DELX,AHS,AHO,ELO(51),EXMAX,XFINAL
     1      ,jray
      COMMON /THRCOM/ VX(30),YMIN,YMAX,XDIV,YDIV
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)
     2      ,JPLT,KREF,KGRAD,KPICT,JPLCT,IPLACE,JCASE,NELO
     3      ,NREF,NRAY,NPRO,NPLCT,NGRAD,SCALE
      COMMON /FORCOM/ DNDZ(100),RM(100),DMDZ(100),KMIR
     1       ,kmgrad,NMIR,NMGRAD,HF(100),DATCTL,Z,LL
      INTEGER DATCTL
      REAL*16 POL(2),TER(4),REFMOD(2,3)
      DATA POL/10HHORIZONTAL,10HVERTICAL  /
      DATA TER/10HSEA WATER ,10HDRY GROUND,10HAVG GROUND,
     1          10HWET GROUND/
      DATA REFMOD/10HFREE SPACE,10H MODEL    ,10HEXPONENTIA,
     1             10HL MODEL   ,10HINPUT PROF,10HILE MODEL /
      DATA CM/2.998D+08/
C
C     SET UP THE NUMBER OF PROGRAM RUNS
      READ 300,NCASE
C     IF DATA CONTROL (DATCTL) = 1, THEN INPUT DATA
C     CONTAINS HEIGHT, N, M, DNDZ, & DMDZ.  IF = 0, THEN
C     INPUT DATA CONTAINS HEIGHT & N ONLY.
      READ 300,DATCTL
      DO 200 ICASE=1,NCASE
C
C     READ AND PRINT THE INPUT DATA
      READ 300,NPRO
      READ 300,NDATA
```

```
      DO 8 ID=1,NDATA
      IF (DATCTL) 4,4,3
    3 READ 320,HF(ID),RN(ID),RM(ID),DNDZ(ID),DMDZ(ID)
      GO TO 5
    4 READ 320,HF(ID),RN(ID)
C     CONVERT HEIGHT DATA FROM METERS TO FEET
    5 HN(ID) = HF(ID) * 3.280840
    8 CONTINUE
      READ 320,AHS,AHO
      READ 320,YMIN,YMAX
      READ 320,XDELTA,XFINAL
      READ 320,ELOS1,ELOS2
      READ 320,FRQ,PW
      READ 300,NHV,NSL,NRMS
      READ 300,KREF,KGRAD,KRAY,KPLOT,KMIR,KMGRAD
      READ 300,NREF,NGRAD,NRAY,NPLOT,NMIR,NMGRAD
C
C     PRINT THE INPUT DATA
      PRINT 330
      PRINT 340,NCASE,NPRO,(REFMOD(IRM,NPRO+1),IRM=1,2),
     1          NDATA
      PRINT 350,AHS,AHO,YMIN,YMAX
      PRINT 360,XDELTA,XFINAL
      PRINT 370,ELOS1,ELOS2
      PRINT 380,FRQ,PW,POL(NHV),TER(NSL),NRMS
      PRINT 390,KREF,KGRAD,KRAY,KPLOT
      PRINT 395,KMIR,KMGRAD
      PRINT 400,NREF,NGRAD,NRAY,NPLOT
      PRINT 405,NMIR,NMGRAD
C     STILL CHECKING INPUTTED DATA
      PRINT 500
      DO 13 ID=1,NDATA
      IF (DATCTL) 12,12,11
```

```
   11 PRINT 510,HF(ID),HN(ID),RN(ID),RM(ID),DNDZ(ID),              ..
    1          DMDZ(ID)                                            ..
      GO TO 13                                                     ..
   12 PRINT 530,HF(ID),HN(ID),RN(ID)                               ..
   13 CONTINUE                                                     ..
C     SET UP INITIAL ATMOSPHERIC REFRACTIVITY CONSTANTS            ..
      IF (NPRO-1) 14,15,20                                         ..
C                                                                  ..
C     FREE SPACE MODEL                                             ..
   14 C1=0.0                                                       ..
      C2=0.0                                                       ..
      GO TO 25                                                     ..
C                                                                  ..
C     EXPONENTIAL MODEL                                            ..
   15 C1=313.0                                                     ..
      C2=0.00004386                                                ..
      GO TO 25                                                     ..
C                                                                  ..
C     PIECE-WISE LINEAR MODEL                                      ..
   20 C2=0.00004386                                                ..
      C1=RN(1)*DEXP(C2*HN(1))                                      ..
C                                                                  ..
C     SET UP INITIAL CONDITIONS                                    ..
   25 C=CMF*CM                                                     ..
      NELO=50                                                      ..
      DENOT=1./FLOAT(NELO)                                         ..
      DELX=CNAUT*XDELTA/10.                                        ..
      EXMAX=CNAUT*XFINAL                                           ..
      FRQ=1000000.0*FRQ                                            ..
      PLACE=EXMAX/DELX                                             ..
      TPW=PW/1000000.0                                             ..
      ICALC=KPLCT+NRAY+NPLCT                                       ..
      IPLACE=IFIX(SNGL(PLACE))+1                                   ..
      IPLCT=NREF+NGRAD+NRAY+NPLCT                                  ..
```

```
      JCASE=ICASE                                                 ..
      JPLT=0                                                      ..
      NELC=NELC+1                                                 ..
C                                                                 ..
C     CALL ROUTINES IF THERE IS A PRINTOUT OR PLOT OF THE         ..
C     REFRACTIVITY PROFILE                                        ..
      JPLCT=1                                                     ..
      IF (NREF) 30,30,31                                          ..
   30 CONTINUE                                                    ..
      IF (KREF) 33,33,32                                          ..
   31 CALL PLOTTR                                                 ..
   32 CALL REFRCT                                                 ..
C                                                                 ..
C     CALL ROUTINES IF THERE IS A PRINTOUT OR PLOT OF THE         ..
C     REFRACTIVITY GRADIENT                                       ..
   33 JPLCT=2                                                     ..
      IF (NGRAD) 34,34,35                                         ..
   34 CONTINUE                                                    ..
      IF (KGRAD) 37,37,36                                         ..
   35 CALL PLOTTR                                                 ..
   36 CALL REFRCT                                                 ..
C                                                                 ..
C     CALL ROUTINES IF THERE IS A PRINTOUT OR PLOT OF THE         ..
C     MODIFIED INDEX OF REFRACTIVITY PROFILE.                     ..
   37 JPLCT = 5                                                   ..
      IF (NMIR) 50,50,51                                          ..
   50 CONTINUE                                                    ..
      IF (KMIR) 53,53,52                                          ..
   51 CALL PLOTTR                                                 ..
   52 CALL REFRCT                                                 ..
C                                                                 ..
C     CALL ROUTINES IF THERE IS A PRINTOUT OR PLOT OF THE         ..
C     MODIFIED INDEX OF REFRACTIVITY GRADIENT.                    ..
   53 JPLCT = 6                                                   ..
```

```
      IF (NMGRAD) 54,54,55
   54 CONTINUE
      IF (KMGRAD) 57,57,56
   55 CALL PLOTTR
   56 CALL REFRCT
C
C     CHECK IF THERE ARE ANY FURTHER CALCULATIONS
   57 IF (ICALC) 200,200,40
C
C     CHECK IF THERE IS TO BE A PLOT OF THE RAY TRACES.
C     IF SO, CALL ROUTINE TO SET UP THE PLOT AXES.
   40 IF (NRAY) 44,44,42
   42 JPLOT=3
      CALL PLOTTR
   44 CONTINUE
C
C     SET UP A LOOP TO CALCULATE THE ALTITUDE PROFILE OF
C     EACH RAY.
      DO 100 I=1,NELO
C
C     INITIALIZE FOR INTEGRATION
      CRH=AHO
      CRX=0.0
      ICCC=I-1
      ELO(I)=ELOS1-DENOT*FLOAT(ICCC)
      EANG=DTR*ELO(I)
      CRG=((RA+CRH)/RA)*DSIN(EANG)/DCOS(EANG)
      JRAY=I
C
C     CALL ROUTINE TO COMPUTE RAY TRACES AND PROPAGATION
C     TIMES.
      CALL RKINTG
  100 CONTINUE
```

```
C     RESET PARAMETER VALUES                                   ..
      DELX=10.*DELX                                            ..
      IPLACE=IPLACE/10+1                                       ..
C                                                              ..
C     CALL ROUTINES IF THERE IS A PRINTOUT OR PLOT OF THE      ..
C     RELATIVE FIELD STRENGTH OR RELATIVE POWER DENSITY.       ..
  120 JPLOT=4                                                  ..
      IF (NPLOT) 130,130,140                                   ..
  130 CONTINUE                                                 ..
      IF (KPLOT) 200,200,150                                   ..
  140 CALL PLOTIF                                              ..
  150 CALL HGAIN                                               ..
  200 CONTINUE                                                 ..
C                                                              ..
C     CALL LIBRARY ROUTINE FOR ON-LINE PLOTTING                ..
      IF (IPLOT) 220,220,210                                   ..
  210 CALL PLOT (0.,0.,999)                                    ..
      PRINT 430                                                ..
  220 CONTINUE                                                 ..
C                                                              ..
  300 FORMAT (6I5)                                             ..
  320 FORMAT (6F10.3)                                          ..
  330 FORMAT (1H1,2X,'ATMOSPHERIC RADIO REFRACTIVITY ',        ..
     1        'COMPUTATIONS'//)                                ..
  340 FORMAT (2X,'   NCASE=',I6/                               ..
     1        2X,'    NPRO=',I6/                               ..
     2        2X,'   MODEL=',5X,2A10/                          ..
     3        2X,'   NDATA=',I6,4X,'LEVELS')                   ..
  350 FORMAT (2X,'     AHS=',F10.2,4X,'FEET'/                  ..
     1        2X,'     AHO=',F10.2,4X,'FEET'/                  ..
     2        2X,'    YMIN=',F10.2,4X,'FEET'/                  ..
     3        2X,'    YMAX=',F10.2,4X,'FEET')                  ..
  360 FORMAT (2X,'  XDELTA=',F10.2,4X,'NAUT MI'/               ..
     1        2X,'  XFINAL=',F10.2,4X,'NAUT MI')               ..
```

```
  370 FORMAT (2X,'    ELOS1=',F10.2,4X,'DEG'/
     1        2X,'    ELOS2=',F10.2,4X,'DEG')
  380 FORMAT (2X,'      FRQ=',F10.2,4X,'MHZ'/
     1        2X,'       PW=',F10.2,4X,'MICROSEC'/
     2        2X,'    POLAR=',5X,A10/
     3        2X,'  TERRAIN=',5X,A10/
     4        2X,'     NRMS=',I6)
  390 FORMAT (2X,'     KREF=',I6/
     1        2X,'    KGRAD=',I6/
     2        2X,'     KRAY=',I6/
     3        2X,'    KPLOT=',I6)
  395 FORMAT (2X,'     KMIR=',I6/
     1        2X,'   KMGRAD=',I6)
  400 FORMAT (2X,'     NREF=',I6/
     1        2X,'    NGRAD=',I6/
     2        2X,'     NRAY=',I6/
     3        2X,'    NPLOT=',I6)
  405 FORMAT (2X,'     NMIR=',I6/
     1        2X,'   NMGRAD=',I6)
  430 FORMAT (5X,'END OF FILE ON PLOTTER TAPE')
  500 FORMAT(/3X,'HT (M)',4X,'HT (FT)',9X,'N',10X,'M',8X,
     1'DNDZ',6X,'DMDZ')
  510 FORMAT(6F11.3)
  530 FORMAT(3F11.3)
      STOP
      END
C*****************************************************************
C*****************************************************************
      SUBROUTINE REFRCT
C
C-----THIS ROUTINE CALCULATES AND PLOTS THE REFRACTIVITY AND
C-----REFRACTIVITY GRADIENT PROFILES
C
```

```
      IMPLICIT REAL*8(A-H,O-Z)                                        ..
      COMMON /ONECOM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2             ..
     1      ,RHC(51,30),PHI(51,30),PI,CMF,CNAUT,DENOT                  ..
     2      ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA                    ..
      COMMON /TWOCOM/ RA,DELX,AHS,AHO,ELO(51),EXMAX,XFINAL            .
     1      ,JRAY                                                      ..
      COMMON /THRCOM/ VX(30),YMIN,YMAX,XDIV,YDIV                      ..
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)               ..
     2      ,JPLT,KREF,KGRAD,KPLOT,JPLOT,IPLACE,JCASE,NELO              ..
     3      ,NREF,NRAY,NPRO,NPLOT,NGRAD,SCALE                          ..
      COMMON /FORCOM/ DNDZ(100),RM(100),DMDZ(100),KMIR                ..
     1       ,KMGRAD,NMIR,NMGRAD,HF(100),DATCTL                        ..
      REAL W,Z                                                         ..
      INTEGER II,LIL                                                   ..
      DIMENSION X(150),Y(150),E(100)                                   ..
C                                                                      ..
C     INITIALIZE THE ARRAYS X AND Y                                    ..
      DO 5 I=1,100                                                     ..
      X(I)=0.0                                                         ..
      Y(I)=0.0                                                         ..
    5 CONTINUE                                                         ..
C                                                                      ..
C     PRINT HEADING IF THERE IS A PRINTOUT                             ..
C     FOR MODIFIED INDEX OF REFRACTIVITY                               ..
      IF (JPLOT-5) 10,6,8                                              ..
    6 CONTINUE                                                         ..
      IF (KMIR) 18,18,7                                                ..
    7 PRINT 130                                                        ..
      GO TO 18                                                         ..
    8 CONTINUE                                                         ..
      IF (KMGRAD) 18,18,9                                              ..
    9 PRINT 135                                                        ..
      GO TO 18                                                         ..
C                                                                      ..
```

```
C     PRINT HEADING IF THERE IS A PRINTOUT
C     FOR REFRACTIVITY
   10 CONTINUE
      IF (JPLOT-1) 11,11,14
   11 CONTINUE
      IF (KREF) 18,18,12
   12 PRINT 110
      GO TO 18
   14 CONTINUE
      IF (KGRAD) 18,18,16
   16 PRINT 120
C
C     SET UP INITIAL CONDITIONS TO CALCULATE REFRACTIVITY
C     AND REFRACTIVITY GRADIENT VERSUS ALTITUDE
   18 CONTINUE
      IF (NPRO-1) 20,20,30
   20 ID=51
      DELH=(YMAX-YMIN)/50.
      A=YMAX+DELH
      GO TO 40
   30 ID=NDATA
      L=0
      M=0
      IF (HN(1)-YMAX) 33,58,58
   33 CONTINUE
      IF (HN(1)-YMIN) 20,35,35
   35 DELH=(YMAX-HN(1))/25.
      A=YMAX+DELH
      ID=25
      M=ID-1
C
C     SET UP A LOOP TO PRINT AND PLOT THE FREE SPACE AND
C     EXPONENTIAL PROFILES.
```

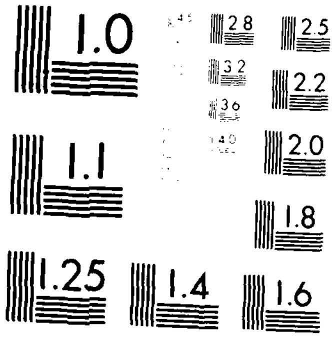
```
   40 CONTINUE
      DO 41 I=1,ID
      A=A-DELH
      X(I)=C1*DEXP(-C2*A)
   41 Y(I)=A
      A=YMAX+DELH
      DO 55 I=1,ID
      A=A-DELH
      IF (JPLOT-1) 42,42,400
  400 CONTINUE
      IF (JPLOT-5) 46,402,410
C
C     PRINT THE REFRACTIVITY PROFILE
   42 X1=X(I)
      Y1=Y(I)
      IF (KREF) 44,44,43
   43 PRINT 140,I,Y1,X1
   44 CONTINUE
      IF (NREF) 54,54,50
C
C     PRINT THE REFRACTIVITY GRADIENT PROFILE
   46 CONTINUE
      IF (I-ID) 47,54,54
   47 X1=3281.0*(X(I)-X(I+1))/(Y(I)-Y(I+1))
      Y1=(Y(I)+Y(I+1))/2.0
      IF (KGRAD) 49,49,48
   48 PRINT 140,I,Y1,X1
   49 CONTINUE
      IF (NGRAD) 54,54,50
C
  402 GO TO 54
  410 GO TO 54
C
```

```
C       PLOT THE REFRACTIVITY AND REFRACTIVITY GRADIENT    ..
C       PROFILES.                                          ..
     50 X1=X1/XDIV                                         ..
        Y1=(Y(I)-YMIN)/YDIV                                ..
        IF (I-1) 51,51,52                                  ..
     51 CALL PLOT (SNGL(X1),SNGL(Y1),3)                    ..
     52 CALL PLOT (SNGL(X1),SNGL(Y1),2)                    ..
        IF (JPLOT-5) 418,54,53                             ..
    418 CONTINUE                                           ..
        IF (JPLOT-1) 54,54,53                              ..
     53 Y2=(Y(I+1)-YMIN)/YDIV                              ..
        CALL PLOT (SNGL(X1),SNGL(Y2),2)                    ..
     54 CONTINUE                                           ..
     55 CONTINUE                                           ..
        IF (NPRO-1) 80,80,56                               ..
C                                                          ..
C       SET UP A LOOP TO PRINT AND PLOT THE PIECE-WISE     ..
C       LINEAR PROFILES.                                   ..
     56 L=ID                                               ..
     58 LP=0                                               ..
        DO 75 I=1,NDATA                                    ..
        IF (HN(I)-YMAX) 60,60,74                           ..
     60 CONTINUE                                           ..
        IF (HN(I)-YMIN) 74,61,61                           ..
     61 L=L+1                                              ..
        LP=LP+1                                            ..
        M=M+1                                              ..
        X(L)=RN(I)                                         ..
        Y(L)=HN(I)                                         ..
        X(L+1)=RN(I+1)                                     ..
        Y(L+1)=HN(I+1)                                     ..
        Z = HF(I) / 1000.0                                 ..
        E(L) = X(I) + (157.0 * Z)                          ..
C                                                          ..
```

AD-A152 819 METEOROLOGICAL CONDITIONS AFFECTING ELECTROMAGNETIC PROPAGATION ON THE ARABIAN PENINSULA(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA W F PETERSEN SEP 84 2/2

UNCLASSIFIED F/G 20/14 NL

END



MICROCOPY RESOLUTION TEST CHART

```
C     NOTE THAT E(I) = RM(I) IF DATCTL = 0,                        ..
C     AND E(L) HAS NO RELATION TO RM(I) IF DATCTL = 1.             ..
      IF (JPLOT-1) 62,62,65                                        ..
C                                                                  ..
C     PRINT THE REFRACTIVITY PROFILE                               ..
   62 X1=X(L)                                                      ..
      Y1=Y(L)                                                      ..
      IF (KREF) 64,64,63                                           ..
   63 PRINT 140,L,Y1,X1                                            ..
   64 CONTINUE                                                     ..
      IF (NREF) 74,74,70                                           ..
C                                                                  ..
C     PRINT THE REFRACTIVITY GRADIENT PROFILE                      ..
   65 CONTINUE                                                     ..
      IF (JPLOT-2) 100,100,200                                     ..
  100 CONTINUE                                                     ..
      IF (DATCTL) 66,66,101                                        ..
  101 X1 = DNDZ(I)                                                 ..
      Y1 = Y(L)                                                    ..
      IF (KGRAD) 69,69,68                                          ..
   66 CONTINUE                                                     ..
      IF (I-NDATA) 67,74,74                                        ..
   67 X1=3281.0*(X(M)-X(M+1))/(Y(M)-Y(M+1))                        ..
      Y1 = Y(L)                                                    ..
      IF (KGRAD) 69,69,68                                          ..
   68 PRINT 140,M,Y1,X1                                            ..
   69 CONTINUE                                                     ..
      IF (NGRAD) 74,74,70                                          ..
C                                                                  ..
C     PRINT THE MODIFIED INDEX OF REFRACTIVITY PROFILE             ..
  200 CONTINUE                                                     ..
      IF (JPLOT-5) 201,201,300                                     ..
  201 CONTINUE                                                     ..
      IF (DATCTL) 204,204,202                                      ..
```

```
  202 X1 = RM(I)
      Y1 = Y(L)
      IF (KMIR) 210,210,208
  204 CONTINUE
      IF (I-NDATA) 206,74,74
  206 X1 = E(L)
      Y1 = Y(L)
      IF (KMIR) 210,210,208
  208 PRINT 140,L,Y1,X1
  210 CONTINUE
      IF (NMIR) 74,74,70
C
C     PRINT THE MODIFIED INDEX OF REFRACTIVITY GRADIENT
C     PROFILES.
  300 CONTINUE
      IF (DATCTL) 304,304,302
  302 X1 = DMDZ(I)
      Y1 = Y(L)
      IF (KGRAD) 312,312,310
  304 CONTINUE
      IF (I-NDATA) 306,74,74
  306 LL = I + 1
      IF (LL .LE. NDATA) GO TO 308
  307 CONTINUE
      DMDZ(I) = (E(L) / HF(I)) * 1000.0
      GO TO 309
  308 W = RN(LL) + (157.0 * (HF(LL) / 1000.0))
      DMDZ(I) = (E(L) - W) / (HF(I) - HF(LL)) * 1000.0
  309 X1 = DMDZ(I)
      Y1 = Y(L)
      IF (KGRAD) 312,312,310
  310 PRINT 140,L,Y1,X1
  312 CONTINUE
      IF (NMGRAD) 74,74,70
```

```
C                                                                    ..
C      PLOT THE REFRACTIVITY, REFRACTIVITY GRADIENT,                 ..
C      MODIFIED INDEX OF REFRACTIVITY,  AND MODIFIED INDEX OF
C      REFRACTIVITY GRADIENT PROFILES.                               ..
   70 X1=X1/XDIV                                                     ..
      Y1=(Y(M)-YMIN)/YDIV                                            ..
      IF (LP-1) 71,71,72                                             ..
   71 CALL PLOT (SNGL(X1),SNGL(Y1),3)                                ..
   72 CALL PLOT (SNGL(X1),SNGL(Y1),2)                                ..
      IF (JPLOT-1) 74,74,73                                          ..
   73 Y2=(Y(M+1)-YMIN)/YDIV                                          ..
      CALL PLOT (SNGL(X1),SNGL(Y2),2)                                ..
   74 CONTINUE                                                       ..
   75 CONTINUE                                                       ..
C                                                                    ..
C      POSITION THE PEN IF THERE HAS BEEN A PLOT                     ..
   80 CONTINUE                                                       ..
      IF (JPLOT-5) 88,82,84                                          ..
   82 CONTINUE                                                       ..
      IF (NMIR) 96,96,94                                             ..
   84 CONTINUE                                                       ..
      IF (NMGRAD) 96,96,94                                           ..
   88 CONTINUE                                                       ..
      IF (JPLOT-1) 90,90,92                                          ..
   90 CONTINUE                                                       ..
      IF (NREF) 96,96,94                                             ..
   92 CONTINUE                                                       ..
      IF (NGRAD) 96,96,94                                            ..
   94 CALL PLOT (0.,0.,-999)                                         ..
      CALL PLOT (2.0,2.0,-3)                                         ..
      CALL FACTOR (SNGL(SCALE))                                      ..
   96 CONTINUE                                                       ..
  106 RETURN                                                         ..
C                                                                    ..
```

```
  110 FORMAT (///23X,'REFRACTIVITY PROFILE'/10X,'I',8X,     ..
     1'ALTITUDE',8X,'REFRACTIVITY'/21X,'(FT)',11X,           ..
     2'(N-UNITS)')                                           ..
  120 FORMAT (///18X,'REFRACTIVITY GRADIENT PROFILE'/10X,    ..
     1'I',8X,'ALTITUDE',7X,'REFF GRADIENT'/21X,'(FT)',9X,    ..
     2'(N-UNITS/KM)')                                        ..
  130 FORMAT (///9X,'MODIFIED INDEX OF REFRACTIVITY ',       ..
     1PROFILE'/10X,'I',8X,'ALTITUDE',5X,'MOD INDEX OF REFR',
     2/21X,'(FT)',11X,'(M-UNITS)')                           ..
  135 FORMAT (///10X,'MODIFIED INDEX OF REFRACTIVITY ',      ..
     1'GRADIENT PROFILE',/10X,'I',8X,'ALTITUDE',7X,          ..
     2'MOD INDEX OF REFR GRADIENT',                          ..
     3/21X,'(FT)',9X,'(M-UNITS/KM)')                         ..
  140 FORMAT (8X,I3,2(6X,F10.2))                             ..
      END                                                    ..
C                                                            ..
C************************************************************
C************************************************************
      SUBROUTINE PKINTG                                      ..
C                                                            ..
C-----THIS ROUTINE SETS UP THE INTEGRATION OF THE RAY        ..
C-----TRAJECTORY AND  TIME OF PROAGATION EQUATIONS  FOR EACH
C-----RAY.  WHEN A RAY CROSSES A BOUNDARY BETWEEN THE        ..
C-----THE PIECE-WISE LINEAR SEGMENTS OF THE REFRACTIVITY     ..
C-----PROFILE OR THE BOUNDARY AT THE EARTH'S SURFACE, THE    ..
C-----RAY EQUATIONS ARE INTEGRATED TO  THE BOUNDARY BY MEANS
C-----OF A VARIABLE STEP SIZE INTERPOLATION ALGORITHM.   THE
C-----RAY EQUATIONS ARE THEN  RE-INITIALIZED AT THE BOUNDARY
C-----AND INTEGRATED TO THE NEXT BOUNDARY, WHERE THE         ..
C-----INTERPOLATION IS REPEATED.                             ..
C                                                            ..
      IMPLICIT REAL*8(A-H,O-Z)                               ..
```

```
      COMMON /CNECCM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2 ..
     1      ,RHC(51,30),PHI(51,30),PI,CMF,CNAUT,DENOT        ..
     2      ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA          ..
      COMMON /TWOCCM/ RA,DELX,AHS,AHO,ELC(51),EXMAX,XFINAL..
     1      ,JRAY                                            ..
      COMMON /THRCCM/ VX(30),YMIN,YMAX,XDIV,YDIV             ..
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)      ..
     2      ,JPLT,KREF,KGRAD,KPICT,JPLOT,IPLACE,JCASE,NELO ..
     3      ,NREF,NRAY,NPRO,NPLCT,NGRAD,SCALE                ..
      COMMON /FCRCCM/ DNDZ(100),RM(100),DMDZ(100),KMIR       ..
     1       ,KMGRAD,NMIR,NMGRAD,HF(100),DATCTL              ..
      DIMENSICN YINT(10),DELXX(5),PINT(10)                   ..
      DATA DELXX,NEQ/10000.D0,1000.D0,100.D0,10.D0,0.D0,2/..
C                                                            ..
C     SET UP INITIAL CONDITIONS                              ..
      DO 5 I=1,10                                            ..
      PINT(I)=0.0                                            ..
    5 YINT(I)=0.0                                            ..
      L=1                                                    ..
      ANGLE=0.0                                              ..
      RHMAG=1.0                                              ..
      STPX=DELX                                              ..
      VX(L)=CRX                                              ..
      H(JRAY,L)=CRH                                          ..
      S(JRAY,L)=DATAN(CRG*RA/(RA+CRH))                       ..
      G(JRAY,L)=PINT(1)                                      ..
      RHO(JRAY,L)=RHMAG                                      ..
      PHI(JRAY,L)=ANGLE                                      ..
      YINT(1)=CRH                                            ..
      YINT(2)=CRG                                            ..
      VALG=YINT(2)                                           ..
      VGTEMP=PINT(1)                                         ..
      VHTEMP=YINT(1)                                         ..
      VXTEMP=CRX                                             ..
```

```
      X=CRX
      ICODE=3
C     II=0
      II=1
C
C     CHECK IF A RAY TRACE IS TO BE MADE
      IF (NRAY) 14,14,7
C
C     TEST FOR MAXIMUM AND MINIMUM ALTITUDES
    7 IF (CRH-YMAX) 8,8,12
    8 IF (CRH-YMIN) 13,10,10
C
C     ALTITUDE BOUNDS NOT EXCEEDED.  POSITION PEN AT
C     EMITTER COORDINATES.
   10 Y=(CRH-YMIN)/YDIV
      CALL PLOT (SNGL(X),SNGL(Y),ICODE)
      ICODE=2
      GO TO 14
C
C     MAXIMUM ALTITIDE EXCEEDED. POSITION PEN AT UPPER
C     LEFT HAND GRAPH CORNER.
   12 Y=(YMAX-YMIN)/YDIV
      CALL PLOT (SNGL(X),SNGL(Y),ICODE)
      GO TO 14
C
C     MINIMUM ALTITIDE EXCEEDED. POSITION PEN AT LOWER
C     LEFT HAND CORNER.
   13 Y=0.0
      CALL PLOT (SNGL(X),SNGL(Y),ICODE)
C
C     FIND WHICH LAYER THE EMITTER IS IN
   14 IF (JRAY-1) 15,15,22
   15 CONTINUE
```

```
      DO 20 I=1,NDATA                                           ..
      IF (CRH-HN(I)) 20,20,16                                   ..
   16 JAREA=I                                                   ..
      JXMTR=I                                                   ..
      GO TO 25                                                  ..
   20 CONTINUE                                                  ..
      GO TO 25                                                  ..
   22 JAREA=JXMTR                                               ..
   25 CONTINUE                                                  ..
C                                                               ..
C     SET UP A LOOP FOR INTEGRATION OF THE ARRAYS "YINT"        ..
C     AND "PINT".                                               ..
      DO 200 I=2,IPLACE                                         ..
      II=II+1                                                   ..
C                                                               ..
C     CALL ROUTINE TO INTEGRATE "YINT" AND "PINT"               ..
      CALL RK (NEQ,CRX,STPX,YINT,PINT)                          ..
C                                                               ..
C     CHECK WHICH LAYER THE RAY IS IN                           ..
  100 KAREA=JAREA                                               ..
      DO 120 J=1,NDATA                                          ..
      IF (YINT(1)-HN(J)) 120,120,110                            ..
  110 KAREA=J                                                   ..
      GO TO 125                                                 ..
  120 CONTINUE                                                  ..
C                                                               ..
C     SET UP LAYER IF RAY HAS INTERSECTED EARTH'S SURFACE.      .
      IF (YINT(1)-AHS) 122,122,125                              ..
  122 KAREA=NDATA+1                                             ..
  125 CONTINUE                                                  ..
C                                                               ..
C     CHECK WHICH LAYER BOUNDARY, IF ANY, HAS BEEN CROSSED      .
C     FIRST.                                                    ..
C                                                               ..
```

```
      IF (JAREA-KAREA) 140,145,130                                 ..
C                                                                  ..
C     AN UPPER BOUNDARY HAS BEEN CROSSED                           ..
  130 BNDRY=HN(JAREA-1)                                            ..
      KAREA=JAREA-1                                                ..
      GO TO 160                                                    ..
C                                                                  ..
C     A LOWER BOUNDARY HAS BEEN CROSSED                            ..
  140 BNDRY=HN(JAREA)                                              ..
      KAREA=JAREA+1                                                ..
      GO TO 160                                                    ..
C                                                                  ..
C     NO BOUNDARY HAS BEEN CROSSED.  STORE ARRAY VALUES            ..
C     EVERY TENTH INTEGRATION STEP.                                ..
  145 IF (II-10) 148,146,146                                       ..
  146 II=0                                                         ..
      L=L+1                                                        ..
      VX(L)=CRX                                                    ..
      H(JRAY,L)=YINT(1)                                            ..
      S(JRAY,L)=DATAN(YINT(2)*RA/(RA+YINT(1)))                     ..
      G(JRAY,L)=PINT(1)                                            ..
      RHO(JRAY,L)=RHMAG                                            ..
      PHI(JRAY,L)=ANGLE                                            ..
  148 VALG=YINT(2)                                                 ..
      VXTEMP=CRX                                                   ..
      VHTEMP=YINT(1)                                               ..
      VGTEMP=PINT(1)                                               ..
      STPX=DELX                                                    ..
C                                                                  ..
C     CHECK IF A RAY TRACE IS TO BE MADE                           ..
      IF (NRAY) 200,200,152                                        ..
C                                                                  ..
C     A RAY TRACE IS TO BE MADE.  CHECK FOR MAXIMUM AND            ..
C     MINIMUM ALTITUDE.                                            ..
```

```
  152 IF (YINT(1)-YMAX) 153,153,156                                  ..
  153 IF (YINT(1)-YMIN) 156,156,154                                  ..
C                                                                    ..
C      MAXIMUM ALTITUDE NOT EXCEEDED.  CALL ROUTINE TO PLOT          .
C      THE RAY.                                                      ..
  154 X=CRX/XDIV                                                     ..
      Y=(YINT(1)-YMIN)/YDIV                                          ..
      CALL PLOT (SNGL(X),SNGL(Y),ICODE)                              ..
      ICODE=2                                                        ..
      GO TO 158                                                      ..
C                                                                    ..
C      MAXIMUM OR MINIMUM ALTITUDE EXCEEDED. TURN OFF PLOTTER
  156 ICODE=3                                                        ..
  158 IF (JAREA-KAREA) 170,200,170                                   ..
C                                                                    ..
C      THE LAYER BOUNDARY HAS BEEN FOUND.   SET UP FOR LINEAR
C      INTERPOLATION SCHEME.                                         ..
  160 DXICT=0.                                                       ..
      HTEMP=YINT(1)                                                  ..
      CRX=VXTEMP                                                     ..
      YINT(1)=VHTEMP                                                 ..
      YINT(2)=VALG                                                   ..
      PINT(1)=VGTEMP                                                 ..
C                                                                    ..
C      SET UP VARIABLE INTEGRATION  STEP SIZE AND INTERPOLATE
C      TO THE BOUNDARY.                                              ..
      DO 165 IJK=1,5                                                 ..
      XX=-YINT(2)/YINT(3)                                            ..
      XYCHK=XX*XX-2.*(YINT(1)-BNDRY)/YINT(3)                         ..
      IF (XYCHK.LT.0.) XYCHK=0.                                      ..
      YY=DSQRT(XYCHK)                                                ..
      CHGX=XX+YY                                                     ..
      IF (XX.GT.YY) CHGX=XX-YY                                       ..
      IF (IJK.GT.4) CHGX=(BNDRY-YINT(1))/YINT(2)                     ..
```

```
      SD=STPX-DXTCT
      IF ((CHGX.LE.0.).OR.(CHGX.GE.SD          )) CHGX=
     1        (STPX-DXTCT)*(BNDRY-YINT(1))/(HTEMP-YINT(1))
      CHGX=CHGX-DELXX(IJK)
      IF (CHGX.LE.0.) GO TO 165
C
C     CALL ROUTINE TO INTEGRATE TO THE BOUNDARY
      CALL RK (NEQ,CRX,CHGX,YINT,PINT)
      DXTCT=DXTCT+CHGX
  165 CONTINUE
C
C     CHECK IF A RAY TRACE IS TO BE MADE
      IF (NRAY-1) 170,152,152
C
C     CHECK IF RAY HAS INTERSECTED EARTH'S SURFACE
  170 IF (KAREA-(NDATA+1)) 190,180,180
C
C     RAY HAS CROSSED ZERO ALTITUDE BOUNDARY.  FIND INCIDENT
C     GRAZING ANGLE.
  180 THETA=DABS(DATAN(YINT(2)))
C
C     CALL ROUTINE TO CALCULATE COMPLEX SCATTERING
C     COEFFICIENT.
      CALL SCATT
C
C     SET UP COMPLEX SCATTERING COEFFICIENT
      RHMAG=RHMAG*ABSRH
      ANGLE=ANGLE+PHASE
C
C     ADD MULTIPATH RAY
      DO 185 LL=2,10
  185 YINT(LL)=-YINT(LL)
      KAREA=NDATA
C
```

```
C     SET UP TO INTEGRATE FROM THE BOUNDARY TO THE NEXT     ..
C     "DELX".                                               ..
  190 JAREA=KAREA                                           ..
      VXTEMP=CRX                                            ..
      VHTEMP=YINT(1)                                        ..
      VALG=YINT(2)                                          ..
      VGTEMP=PINT(1)                                        ..
      STPX=STPX-DXTOT                                       ..
C                                                           ..
C     CALL ROUTINE TO INTEGRATE FROM THE BOUNDARY TO THE    ..
C     NEXT "DELX".                                          ..
      CALL RK  (NEQ,CRX,STPX,YINT,PINT)                     ..
C                                                           ..
C     CHECK FOR MORE BOUNDARY CROSSINGS                     ..
      GO TO 100                                             ..
  200 CONTINUE                                              ..
      ICODE=3                                               ..
      IF (NRAY) 230,230,210                                 ..
  210 CALL PLOT (SNGL(X),SNGL(Y),ICODE)                     ..
C                                                           ..
C     CHECK IF THIS IS A PLOT OF THE LAST RAY.  IF SO,      ..
C     POSITION THE PEN FOR THE NEXT PLOT.                   ..
      IF (JRAY-NELC) 230,220,220                            ..
  220 CALL PLOT (0.,0.,-999)                                ..
      CALL PLOT (2.0,2.0,-3)                                ..
      CALL FACTOR (SNGL(SCALE))                             ..
  230 CONTINUE                                              ..
      RETURN                                                ..
      END                                                   ..
C                                                           ..
```

```
C*****************************************************************
C*****************************************************************
      SUBROUTINE RK (N,XN,H,Y,P)                                   ..
C                                                                  ..
C-----THIS ROUTINE INTEGRATES THE RAY TRAJECTORY AND TIME OF
C-----PROPAGATION DIFFERENTIAL EQUATIONS BY MEANS OF A             ..
C-----FOURTH ORDER RUNGE-KUTTA ALGORITHM USING AN                  ..
C-----INTEGRATION STEP SIZE OF H = XDELTA/10, WHERE XDELTA         .
C-----IS THE DISTANCE INTERVAL ALONG THE EARTH'S SURFACE           ..
C-----FOR PRINTING AND PLOTTING THE  HEIGHT GAIN CURVES,  OR
C-----H = CHGX WHERE CHGX IS A VARIABLE STEP SIZE SET BY THE
C-----INTERPOLATION ALGORITHM IN SUBROUTINE RKINTG.                ..
C                                                                  ..
      IMPLICIT REAL*8(A-H,O-Z)                                     ..
      DIMENSION Y(10),P(10),YDOT(10),PDOT(10),Q(10,4)              ..
     1,R(10,4),YN(10),PN(10)                                       ..
C                                                                  ..
C     SET UP INITIAL CONDITIONS                                    ..
      DO 5 I=1,N                                                   ..
      YN(I)=Y(I)                                                   ..
    5 PN(I)=P(I)                                                   ..
C                                                                  ..
C     SET UP A LOOP TO INTEGRATE THE DIFFERENTIAL EQUATIONS
      DO 60 L=1,4                                                  ..
C                                                                  ..
C     CALL ROUTINE TO SET UP THE DIFFERENTIAL EQUATIONS            ..
      CALL ATMOS (Y,P,YDOT,PDOT)                                   ..
C                                                                  ..
C     INTEGRATE THE DIFFERENTIAL EQUATIONS                         ..
      GO TO (10,20,30,40),L                                        ..
   10 DO 15 K=1,N                                                  ..
      Q(K,L)=H*YDOT(K)                                             ..
   15 Y(K)=YN(K)+Q(K,L)/2.                                         ..
```

```
      R(1,I)=H*PDOT(1)                                          ..
      P(1)=PN(1)+R(1,L)/2.                                      ..
      X=XN+H/2.                                                 ..
      GO TO 50                                                  ..
   20 DO 25 K=1,N                                               ..
      Q(K,L)=H*YDOT(K)                                          ..
   25 Y(K)=YN(K)+Q(K,L)/2.                                      ..
      R(1,I)=H*PDOT(1)                                          ..
      P(1)=PN(1)+R(1,L)/2.                                      ..
      X=XN+H/2.                                                 ..
      GO TO 50                                                  ..
   30 DO 35 K=1,N                                               ..
      Q(K,L)=H*YDOT(K)                                          ..
   35 Y(K)=YN(K)+Q(K,L)                                         ..
      R(1,L)=H*PDOT(1)                                          ..
      P(1)=PN(1)+R(1,L)                                         ..
      X=XN+H                                                    ..
      GO TO 50                                                  ..
   40 DO 45 K=1,N                                               ..
      Q(K,L)=H*YDOT(K)                                          ..
   45 Y(K)=YN(K)+(Q(K,1)+2.0*Q(K,2)+2.0*Q(K,3)+Q(K,4))/6.0      .
      R(1,I)=H*PDOT(1)                                          ..
      P(1)=PN(1)+(R(1,1)+2.0*R(1,2)+2.0*R(1,3)+R(1,4))/6.0      .
      XN=XN+H                                                   ..
   50 CONTINUE                                                  ..
   60 CONTINUE                                                  ..
C                                                               ..
C     CALL ROUTINE TO FIND THE VALUES OF THE DIFFERENTIAL       ..
C     EQUATIONS AT THE END OF THE INTEGRATION STEP.             ..
      CALL ATMOS (Y,P,YDOT,PDOT)                                ..
C                                                               ..
C     STORE THE NEW DERIVATIVE OF THE RAY SLOPE                 ..
      Y(3)=YDOT(2)                                              ..
      RETURN                                                    ..
```

```
      END                                                          ..
C                                                                  ..
C*************************************************************************
C*************************************************************************
      SUBROUTINE ATMOS (Y,P,YDOT,PDOT)                             ..
C                                                                  ..
C-----THIS ROUTINE COMPUTES ATMOSPHERIC REFRACTIVITY AT             ..
C-----THE RAY ALTITUDE AND SETS UP THE RAY DIFFERENTIAL             ..
C-----EQUATIONS.                                                   ..
C                                                                  ..
      IMPLICIT REAL*8(A-H,O-Z)                                     ..
      COMMON /ONECOM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2          .
     1      ,RHO(51,30),PHI(51,30),PI,CMF,CNAUT,DENOT              ..
     2      ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA                ..
      COMMON /TWOCOM/ RA,DELX,ABS,AHO,ELC(51),EXMAX,XFINAL         .
     1      ,JRAY                                                  ..
      COMMON /THRCOM/ VX(30),YMIN,YMAX,XDIV,YDIV                   ..
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)            ..
     2      ,JPLT,KREF,KGRAD,KPICT,JPLOT,IPLACE,JCASE,NELO         .
     3      ,NREF,NRAY,NPRO,NPLOT,NGRAD,SCALE                      ..
      COMMON /FORCOM/ DNDZ(100),RM(100),DMDZ(100),KMIR,            ..
     1       ,KMGRAD,NMIR,NMGRAD,HF(100),DATCTL                    ..
      DIMENSION Y(10),P(10),YDOT(10),PDOT(10)                      ..
C                                                                  ..
C     SET UP INITIAL CONDITIONS                                    ..
      CH=Y(1)                                                      ..
      CG=Y(2)                                                      ..
C                                                                  ..
C     TEST FOR THE APPROPRIATE ATMOSPHERIC MODEL                   ..
      IF (NPRO-1) 10,10,20                                         ..
C                                                                  ..
C     FREE SPACE AND EXPONENTIAL MODELS                            ..
   10 REFR=C1*DEXP(-C2*CH)                                         ..
      DLNDH=-C2*REFR*1.0E-06/(REFR*1.0E-06 + 1.0)                  ..
```

```
      GO TO 100
C
C     THE ATMOSPHERE IS STRATIFIED.   SELECT THE APPROPRIATE
C     MODEL.
   20 IF (JAREA-1) 50,50,60
C
C     ALTITUDE IS ABOVE THE HIGHEST REFRACTIVITY PROFILE
C     DATA POINT.  USE AN EXPONENTIAL MODEL WHICH FITS THE
C     DATA.
   50 REFR=C1*DEXP(-C2*CH)
      DLNDH=-C2*REFR*1.0E-06/(REFR*1.0E-06 + 1.0)
      GO TO 100
C
C     ALTITUDE IS BELOW THE HIGHEST REFRACTIVITY PROFILE
C     DATA POINT.  USE A PIECE-WISE LINEAR MODEL.
   60 SLOPE=(RN(JAREA-1)-RN(JAREA))/(HN(JAREA-1)-HN(JAREA))
      B=RN(JAREA)-SLOPE*HN(JAREA)
C
C     COMPUTE REFRACTIVITY FOR THE PIECE-WISE LINEAR MODEL
   30 REFR=SLOPE*CH + B
      DLNDH=(SLOPE*1.0E-06)/(REFR*1.0E-06 + 1.0)
C
C     COMPUTE THE DERIVATIVES FOR RAY TRACES
  100 RAD=RA+CH
      YDOT(2)=DLNDH*((RAD/RA)**2 + CG**2) + (2.0/RAD)*CG**2
     1 + RAD/RA**2
      YDOT(1)=CG
C
C     COMPUTE THE DERIVATIVE FOR TIME OF PROPAGATION
      PDOT(1)=RAD*(REFR*1.0E-06+1.0)
     1*DSQRT(1.0+(RA*CG/RAD)**2)/(C*RA)
      RETURN
      END
C
```

```
C*****************************************************************
C*****************************************************************
      SUBROUTINE SCATT                                          ..
C                                                               ..
C-----THIS ROUTINE CALCULATES THE COMPLEX SPECULAR              ..
C-----SCATTERING COEFFICIENT FOR WAVEFRONT REFLECTION FROM       .
C-----SMOOTH OR ROUGH LAND AND SEA SURFACES.                    ..
C                                                               ..
      IMPLICIT REAL*8(A-H,O-Z)                                  ..
      COMMON /CNECOM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2        .
     1     ,RHO(51,30),PHI(51,30),PI,CMF,CNAUT,DENOT            ..
     2     ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA              ..
      DIMENSION EPS(3,2),SIGMA(3,2),DELHSL(9,2)                 ..
      REAL NI,NR                                                ..
      DATA EPS,IC/80.D0,69.D0,65.D0,4.D0,10.D0,30.D0,0/         ..
      DATA SIGMA/4.3D0,6.5D0,1.6D1,1.D-4,1.6D-3,1.0D-2/         ..
      DATA DELHSL/0.D0,2.0D-1,6.0D-1,1.1D0,1.7D0,2.6D0          ..
     1,4.3D0,8.6D0,1.29D1,0.D0,9.D0,30.D0,56.D0,112.D0          ..
     2,214.D0,429.D0,1288.D0                                    ..
     3,2.146D3/                                                 ..
C                                                               ..
C     SET UP INITIAL CONDITIONS                                 ..
      IF (IC) 10,10,50                                          ..
   10 IC=1                                                      ..
      JJ=NRMS+1                                                 ..
      IF (NSL-1) 12,12,30                                       ..
   12 KK=1                                                      ..
      IF (FRQ-1500000000.) 14,16,16                             ..
   14 II=1                                                      ..
      GO TO 40                                                  ..
   16 IF (FRQ-5000000000.) 18,20,20                             ..
   18 II=2                                                      ..
      GO TO 40                                                  ..
```

```
   20 II=3
      GO TO 40
   30 KK=2
      II=NSL-1
C
C     CALCULATE THE COMPLEX DIELECTRIC CONSTANT
   40 ER=EPS(II,KK)
      EI=60.0*SIGMA(II,KK)*C/(CMF*FRQ)
      A=DSQRT(ER**2+EI**2)
      ALPHA=DATAN2(EI,ER)
      DELTAH=DELHSL(JJ,KK)
C
C     CHECK WHICH POLARIZATION IS BEING USED
   50 IF (NHV-1) 60,60,70
C
C     HORIZONTAL POLARIZATION
   60 NR=DSIN(THETA)-DSQRT(A)*DCOS(ALPHA/2.)
      NI=DSQRT(A)*DSIN(ALPHA/2.)
      DR=DSIN(THETA)+DSQRT(A)*DCOS(ALPHA/2.)
      DI=DSQRT(A)*DSIN(ALPHA/2.)
      GR=(NR*DR-NI*DI)/(DR**2+DI**2)
      GI=(NR*DI+NI*DR)/(DR**2+DI**2)
      GO TO 80
C
C     VERTICAL POLARIZATION
   70 NR=DSQRT(A)*DCOS(ALPHA/2.)*DSIN(THETA)-1.0
      NI=DSQRT(A)*DSIN(ALPHA/2.)*DSIN(THETA)
      DR=DSQRT(A)*DCOS(ALPHA/2.)*DSIN(THETA)+1.0
      DI=DSQRT(A)*DSIN(ALPHA/2.)*DSIN(THETA)
      GR=(NR*DR+NI*DI)/(DR**2+DI**2)
      GI=(NR*DI-NI*DR)/(DR**2+DI**2)
C
C     CALCULATE THE COMPLEX FRESNEL REFLECTION COEFFICIENT
   80 ABSRH=DSQRT(GR**2+GI**2)
```

```
      PHASE=DATAN2(-GI,GR)                                        ..
C                                                                 ..
C     CALCULATE THE TOTAL SPECULAR REFLECTION COEFFICIENT         ..
      ABSRH=ABSRH*DEXP(-0.5*(4.0*PI*DELTAH*DSIN(THETA)            ..
     1 *FRQ/C)**2)                                                ..
      RETURN                                                      ..
      END                                                         ..
C                                                                 ..
C*****************************************************************
C*****************************************************************
      SUBROUTINE HGAIN                                            ..
C                                                                 ..
C-----THIS ROUTINE COMPUTES FIELD STRENGTH AND POWER DENSITY
C-----HEIGHT-GAIN FUNCTIONS (ONE-WAY FIELD STRENGTH AND           ..
C-----POWER DENSITY NORMALIZED TO FREE SPACE VALUES) AT           ..
C-----"XDELTA" DISTANCE  INTERVALS ALONG THE SURFACE  OF THE
C-----EARTH.  HEIGHT-GAINS ARE OBTAINED FROM CALCULATIONS AT
C-----200 "WINDOWS", OR ALTITUDE INCREMENTS, EXTENDING           ..
C-----VERTICALLY BETWEEN THE HIGHEST  AND LOWEST RAYS WITHIN
C-----THE SPECIFIED PLOT LIMITS.                                  ..
C                                                                 ..
      IMPLICIT REAL*8(A-H,O-Z)                                    ..
      COMMON /ONECOM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2         ..
     1      ,RHO(51,30),PHI(51,30),PI,CMF,CNAUT,DENOT             ..
     2      ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA               ..
      COMMON /TWOCOM/ RA,DELX,AHS,AHO,ELO(51),EXMAX,XFINAL        .
     1      ,JRAY                                                 ..
      COMMON /THRCOM/ VX(30),YMIN,YMAX,XDIV,YDIV                  ..
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)           ..
     2      ,JPLT,KREF,KGRAD,KPICT,JPLOT,IPLACE,JCASE,NELO        .
     3      ,NREF,NRAY,NPRO,NPLOT,NGRAD,SCALE                     ..
      COMMON /FORCOM/ DNDZ(100),RM(100),DMDZ(100),KMIR            ..
     1       ,KMGRAD,NMIR,NMGRAD,HF(100),DATCTL                   ..
```

```
      DIMENSION L(51),TDIFF(30),ESIG(30),PSC(30)                       ..
     1,TSIG(30),ESIGT(30),PSCT(30),TSIGT(30)                            ..
      DATA ZDIV/40.0D0/                                                 ..
C                                                                       ..
C     SET UP INITIAL CONDITIONS                                         ..
      DO 5 I=1,30                                                       ..
      TDIFF(I)=0.0                                                      ..
      ESIG(I)=0.0                                                       ..
      PSC(I)=0.0                                                        ..
      TSIG(I)=0.0                                                       ..
      ESIGT(I)=0.0                                                      ..
      PSCT(I)=0.0                                                       ..
      TSIGT(I)=0.0                                                      ..
    5 CONTINUE                                                          ..
      DO 6 I=1,51                                                       ..
      L(I)=0.0                                                          ..
    6 CONTINUE                                                          ..
      R1=RA+AHC                                                         ..
      XN=DELX/XDIV                                                      ..
      YN=YMAX/YDIV                                                      ..
      YS=AHS/YDIV                                                       ..
      NP=200                                                            ..
C                                                                       ..
C     SET UP A LOOP TO  CALCULATE RELATIVE FIELD STRENGTH OR
C     POWER DENSITY AT EACH INCREMENT OF DISTANCE.                      ..
      DO 1000 K=2,IPLACE                                                ..
      HLO=YMAX                                                          ..
      U=VX(K)/RA                                                        ..
C                                                                       ..
C     FIND HIGHEST AND LOWEST RAYS                                      ..
      DO 100 I=1,NELC                                                   ..
      HLO=DMIN1(HLO,H(I,K))                                             ..
  100 CONTINUE                                                          ..
      HHI=DMIN1(H(1,K),YMAX)                                            ..
```

```
      HDIFF=HHI-HLC                                                   ..
      HTB=DABS(H(1,K)-H(2,K))                                         ..
C                                                                     ..
C     EXIT IF ALL RAYS EQUAL OR EXCEED THE MAXIMUM ALTITUDE
      IF (HLO-YMAX) 150,1100,1100                                     ..
C                                                                     ..
C     SET UP WINDOW SIZE AND WINDOW POSITIONS TO EXCLUDE THE
C     HIGHEST AND LOWEST RAYS.                                        ..
  150 WINDOW=HDIFF/190.                                               ..
      HNOW=HHI-WINDOW/10.                                             ..
      HFINAL=HLC+WINDOW/10.                                           ..
      RWP=HNOW-HFINAL                                                 ..
C                                                                     ..
C     FIND THE ALTITUDE INCREMENT FOR EACH NEW WINDOW                 ..
C     POSITION.                                                       ..
      DH=RWP/FLOAT(NP)                                                ..
      HNOW=HNOW+DH                                                    ..
C                                                                     ..
C     SET UP A LOOP TO POSITION THE WINDOW EVERY "DH" FEET            .
C     IN ALTITUDE.                                                    ..
      DO 900 J=1,NP                                                   ..
      HNOW=HNOW-DH                                                    ..
C                                                                     ..
C     CALCULATE THE UPPER ANGLE LIMIT SUBTENDED BY THE                ..
C     WINDOW IN FREE SPACE.                                           ..
      R2=RA+HNOW                                                      ..
      DSQ=R1**2 + R2**2 - 2.0*R1*R2*DCOS(U)                           ..
      E1=DARCOS((DSQ + (R1*DTAN(U))**2 - (R1/DCOS(U)-R2)**2)
     1/(2.0*R1*DTAN(U)*DSQRT(DSQ)))                                   ..
      IF (R1/DCOS(U).GT.R2) E1=-E1                                    ..
C                                                                     ..
C     CALCULATE THE LOWER ANGLE LIMIT SUBTENDED BY THE                ..
C     WINDOW IN FREE SPACE.                                           ..
      R2=RA+HNOW-WINDOW                                               ..
```

```
      DSQ=R1**2 + R2**2 - 2.0*R1*R2*DCOS(U)                       ..
      E2=DARCOS((DSQ + (R1*DTAN(U))**2 - (R1/DCOS(U)-R2)**2)
     1/(2.0*R1*DTAN(U)*DSQRT(DSQ)))                                ..
      IF (R1/DCOS(U).GT.R2) E2=-E2                                 ..
      EDIFF=DSQRT(DABS(E1-E2)/DIR)                                 ..
C                                                                  ..
C     CALCULATE THE ELEVATION ANGLE OF THE EMITTER AT THE          ..
C     WINDOW.                                                      ..
      R1=RA+HNOW-WINDOW/2.                                         ..
      R2=RA+AHC                                                    ..
      DSQ=R1**2 + R2**2 - 2.0*R1*R2*DCOS(U)                       ..
      A0=DARCOS((DSQ + (R1*DTAN(U))**2 - (R1/DCOS(U)-R2)**2)
     1/(2.0*R1*DTAN(U)*DSQRT(DSQ)))                                ..
      IF (R1/DCOS(U).GT.R2) A0=-A0                                 ..
C                                                                  ..
C     SET UP THE WINDOW ALTITUDE PLUS ITS UPPER AND LOWER          ..
C     BOUNDARIES.                                                  ..
      HUP=HNOW                                                     ..
      HH=HNOW-WINDOW/2.                                            ..
      HDN=HNOW-WINDOW                                              ..
C                                                                  ..
C     SET UP CONTROL INTEGERS FOR EACH RAY                         ..
      DO 220 I=1,NELC                                              ..
      IF (H(I,K)-HUP) 200,200,210                                  ..
  200 IF (H(I,K)-HDN) 215,205,205                                  ..
  205 L(I)=2                                                       ..
      GO TO 220                                                    ..
  210 L(I)=3                                                       ..
      GO TO 220                                                    ..
  215 L(I)=1                                                       ..
  220 CONTINUE                                                     ..
C                                                                  ..
C     SET UP INITIAL CONDITIONS                                    ..
      E=0.0                                                        ..
```

```
      JSLOPE=0                                                        ..
      LC=0                                                            ..
      KTOT=0                                                          ..
      MEL=NELO-1                                                      ..
      DO 225 IFS=1,2                                                  ..
      TDIFF(IFS)=0.0                                                  ..
  225 ESIG(IFS)=0.0                                                   ..
C                                                                     ..
C     SET UP A LOOP WHICH  SCANS RAY HEIGHT VERSUS ELEVATION
C     ANGLE.                                                          ..
      DO 600 I=1,MEL                                                  ..
      IF (I-1) 226,226,230                                            ..
  226 IF (L(1)-2) 230,600,230                                         ..
  230 JLAST=JSLOPE                                                    ..
      JC=IABS(L(I)-L(I+1))                                            ..
      IF (L(I)-L(I+1)) 260,600,240                                    ..
C                                                                     ..
C     NORMAL RAY ORDER                                                ..
  240 JSLOPE=1                                                        ..
      IF (JLAST-1) 280,280,310                                        ..
C                                                                     ..
C     INVERTED RAY ORDER                                              ..
  260 JSLOPE=2                                                        ..
      IF (JLAST-1) 280,310,280                                        ..
C                                                                     ..
C     EITHER ONE OR TWO WINDOW LIMIT CROSSINGS                        ..
  280 IF (JC-1) 300,300,380                                           ..
C                                                                     ..
C     ONE WINDOW LIMIT CROSSING                                       ..
  300 LC=LC+1                                                         ..
      IF (LC-1) 340,340,360                                           ..
C                                                                     ..
C     RAY ORDER REVERSAL OCCURS.  CHECK IF ONE OR TWO                 ..
C     WINDOW LIMIT CROSSINGS.                                         ..
```

```
  310 IF (JC-1) 320,320,230                                          ..
C                                                                    ..
C     ONE WINDOW LIMIT CROSSING.  CHECK IF RAY REVERSAL              ..
C     OCCURS INSIDE OR OUTSIDE THE WINDOW                            ..
  320 IF (LC) 230,230,560                                            ..
C                                                                    ..
C     FIRST WINDOW LIMIT CROSSING                                    ..
  340 J1=I                                                           ..
      GO TO 600                                                      ..
C                                                                    ..
C     SECOND WINDOW CROSSING                                         ..
  360 J2=I+1                                                         ..
C                                                                    ..
C     FIND WHICH RAYS LIE ABOVE AND BELOW THE WINDOW CENTER
      DO 370 J12=J1,J2                                               ..
      IF (JSLOPE-1) 362,362,364                                      ..
  362 IF (HH-H(J12+1,K)) 370,366,366                                 ..
  364 IF (HH-H(J12+1,K)) 366,366,370                                 ..
  366 K1=J12                                                         ..
      K2=J12+1                                                       ..
      GO TO 440                                                      ..
  370 CONTINUE                                                       ..
C                                                                    ..
C     BOTH WINDOW LIMITS CROSSED.  CHECK FOR "RADIO HOLE"            ..
  380 IF (DABS(H(I,K)-H(I+1,K))-5.0*HTB) 390,390,560                 ..
C                                                                    ..
C     BOTH WINDOW LIMITS CROSSED.   NO "RADIO HOLE" HAS BEEN
C     FOUND.                                                         ..
  390 J1=I                                                           ..
      J2=I+1                                                         ..
      K1=J1                                                          ..
      K2=J2                                                          ..
C                                                                    ..
```

```
C     THE INCREMENT OF RAYS AT THE WINDOW HAS BEEN FOUND. ..
C     CHECK IF RAY ORDER IS NORMAL OR INVERTED.            ..
  440 IF (JSLOPE-1) 460,460,480                             ..
C                                                          ..
C     NORMAL RAY ORDER.  CALCULATE THE UPPER AND LOWER     ..
C     ANGLES SUBTENDED BY THE WINDOW.                      ..
  460 EUP=ELO(J1)-DENCT*(H(J1,K)-HUP)/(H(J1,K)-H(J1+1,K))  ..
      EDN=ELO(J2)+DENCT*(HDN-H(J2,K))/(H(J2-1,K)-H(J2,K))  ..
      E=DSQRT(EUP-EDN)                                     ..
      PSCAT=PHI(J1,K)                                      ..
      RSCAT=RHO(J1,K)                                      ..
      GO TO 500                                            ..
C                                                          ..
C     INVERTED RAY ORDER.  CALCULATE THE UPPER AND LOWER   ..
C     ANGLES SUBTENDED BY THE WINDOW.                      ..
  480 EUP=ELO(J2)+DENCT*(H(J2,K)-HUP)/(H(J2,K)-H(J2-1,K))  ..
      EDN=ELO(J1)-DENCT*(HDN-H(J1,K))/(H(J1+1,K)-H(J1,K))  ..
      E=DSQRT(EDN-EUP)                                     ..
      PSCAT=PHI(J2,K)                                      ..
      RSCAT=RHO(J2,K)                                      ..
C                                                          ..
C     SET UP INITIAL CONDITIONS  TO CALCULATE MEAN ELEVATION
C     ANGLE AND MEAN TIME OF ARRIVAL.                      ..
  500 KTOT=KTOT+1                                          ..
      TSIGT(KTOT)=G(K1,K)-(G(K1,K)-G(K2,K))*(H(K1,K)-HH)   ..
     1/(H(K1,K)-H(K2,K))                                   ..
      ALPH=-S(K1,K)+(S(K1,K)-S(K2,K))*(H(K1,K)-HH)         ..
     1/(H(K1,K)-H(K2,K))                                   ..
C                                                          ..
C     CALCULATE ANGLE INCREMENT OF EACH WAVEFRONT          ..
      ESIGT(KTOT)=E*RSCAT*DSQRT(DCOS(A0)/DCOS(ALPH))       ..
      PSCT(KTOT)=PSCAT                                     ..
C                                                          ..
```

```
C     RESET INITIAL CONDITIONS TO CONTINUE SCAN OF             ..
C     HEIGHT VS ANGLE.                                         ..
  560 LC=0                                                     ..
  600 CONTINUE                                                 ..
C                                                              ..
C     CHECK IF WINDOW IS IN A SHADOW REGION RESULTING FROM A
C     CAUSTIC.                                                 ..
      IF (KTOT) 780,780,610                                    ..
C                                                              ..
C     WINDOW IS NOT IN A SHADOW REGION.  PUT WAVEFRONTS IN .
C     ORDER OF THEIR TIMES-OF-ARRIVAL.                         ..
  610 CONTINUE                                                 ..
      DO 660 IS=1,KTOT                                         ..
      TMIN=10.0                                                ..
      DO 650 IR=1,KTOT                                         ..
      TMIN=DMIN1(TMIN,TSIGT(IR))                               ..
      IF (TMIN-TSIGT(IR)) 640,630,640                          ..
  630 IMIN=IR                                                  ..
  640 CONTINUE                                                 ..
  650 CONTINUE                                                 ..
      TSIG(IS)=TSIGT(IMIN)                                     ..
      ESIG(IS)=ESIGT(IMIN)                                     ..
      PSC(IS)=PSCI(IMIN)                                       ..
      TSIGT(IMIN)=20.0                                         ..
  660 CONTINUE                                                 ..
C                                                              ..
C     CHECK IF MORE THAN ONE WAVEFRONT IS PRESENT IN THE       ..
C     WINDOW.                                                  ..
      IF (KTOT-1) 700,700,665                                  ..
C                                                              ..
C     CALCULATE TIME DIFFERENCE OF ARRIVAL (T.D.O.A.)          ..
C     BETWEEN WAVEFRONTS.                                      ..
  665 CONTINUE                                                 ..
```

```
      DO 670 IT=2,KTCT                                                ..
  670 TDIFF(IT)=ESIG(IT)-TSIG(1)                                      ..
C                                                                     ..
C     SET UP A LOOP TO CALCULATE TOTAL FIELD STRENGTH OR              ..
C     POWER DENSITY IF WAVEFRONTS OVERLAP IN TIME.                    ..
  700 ESUM=0.0                                                        ..
      DO 720 IFI=1,KTCT                                               ..
      IF (TDIFF(IFI)-TPW) 710,710,720                                 ..
  710 ESUM=ESUM+ESIG(IFI)*DCOS(PSC(IFI)-2.0*PI*FRQ                    ..
     1*TDIFF(IFI))                                                    ..
  720 CONTINUE                                                        ..
      ESUM=DABS(ESUM)                                                 ..
C                                                                     ..
C     CHECK IF FIELD STRENGTH IS TOO LOW FOR CALCULATION              ..
      IF (ESUM/EDIFF-0.00000001) 780,730,730                          ..
C                                                                     ..
C     CHECK IF FIELD STRENGTH OR POWER DENSITY IS TO BE               ..
C     COMPUTED.                                                       ..
  730 IF (NPLOT-1) 740,750,760                                        ..
  740 IF (KPLOT-1) 750,750,760                                        ..
C                                                                     ..
C     CALCULATE TOTAL RELATIVE FIELD STRENGTH.                        ..
  750 SP=10.*DLOG10(ESUM/EDIFF)                                       ..
      GO TO 800                                                       ..
C                                                                     ..
C     CALCULATE TOTAL RELATIVE POWER DENSITY.                         ..
  760 SP=20.*DLOG10(ESUM/EDIFF)                                       ..
      GO TO 800                                                       ..
C                                                                     ..
C     SET FIELD STRENGTH AND POWER DENSITY FOR A SHADOW               ..
C     REGION.                                                         ..
  780 SP=-1000000.0                                                   ..
C                                                                     ..
```

```
C     PRINT HEADING AND RAY HEIGHTS IF THIS IS A NEW                  ..
C     DISTANCE.                                                       ..
  800 IF (J-1) 810,810,820                                            ..
  810 CONTINUE                                                        ..
      XNAUT=VX(K)/CNAUT                                               ..
      IF (KPLOT-1) 816,812,814                                        ..
  812 PRINT 1200,XNAUT                                                ..
      GO TO 816                                                       ..
  814 PRINT 1210,XNAUT                                                ..
C                                                                     ..
C     POSITION THE PEN AND DRAW THE NEW CRDINATE AXES IF              ..
C     THERE IS A PLOT.                                                ..
  816 IF (NPLOT) 820,820,818                                          ..
  818 CALL PLOT (SNGL(XN),0.0,-3)                                     ..
      CALL PLOT (0.0,SNGL(YS),3)                                      ..
      CALL PLOT (0.0,SNGL(YN),2)                                      ..
      CALL PLOT (0.0,0.0,3)                                           ..
      ICODE=3                                                         ..
C                                                                     ..
C     PRINT THE RELATIVE FIELD STRENGTH OR POWER DENSITY AND
C     NUMBER OF WAVEFRONTS IN HEIGHT-GAIN CALCULATIONS.               ..
  820 IF (KPLOT) 840,840,830                                          ..
  830 PRINT 1220,J,HH,SP                                              ..
C                                                                     ..
C     SET PARAMETERS IF THERE IS A PLOT.                              ..
  840 IF (NPLOT) 900,900,850                                          ..
  850 Y=HH/YDIV                                                       ..
C                                                                     ..
C     CHECK IF FIELD STRENGTH OR POWER DENSITY IS TOO LOW             ..
C     FOR PLOTTING.                                                   ..
      IF (SP+40.0) 860,870,870                                        ..
C                                                                     ..
C                                                                     ..
```

```
C      FIELD STRENGTH OR POWER DENSITY LESS THAN -40 DB.          ..
C      TURN OFF PLOTTER.                                          ..
  860 X=-40.0/ZDIV                                                ..
      CALL PLOT (SNGL(X),SNGL(Y),ICODE)                           ..
      ICODE=3                                                     ..
      GO TO 900                                                   ..
C                                                                 ..
C      PLOT TOTAL RELATIVE FIELD STRENGTH OR POWER DENSITY.       .
  870 X=SP/ZDIV                                                   ..
      IF (J-1) 880,880,882                                        ..
  880 ICODE=3                                                     ..
      GO TO 884                                                   ..
  882 ICODE=2                                                     ..
  884 CALL PLOT (SNGL(X),SNGL(Y),ICODE)                           ..
  900 CONTINUE                                                    ..
 1000 CONTINUE                                                    ..
C                                                                 ..
C      POSITION THE PEN IF THERE HAS BEEN A PLOT.                 ..
 1100 IF (NPLOT) 1120,1120,1110                                   ..
 1110 CALL PLOT (0.,0.,-999)                                      ..
      CALL PLOT (2.0,2.0,-3)                                      ..
      CALL FACTOR (SNGL(SCALE))                                   ..
 1120 CONTINUE                                                    ..
      RETURN                                                      ..
C                                                                 ..
 1200 FORMAT (////,1X,'PRINTOUT OF FIELD STRENGTH AND ',          ..
     1'T.D.O.A. S AT X =',F8.2,2X,'NAUTICAL MILES',               ..
     2//5X,'NO.',8X,'HEIGHT (FT)',6X,'FIELD STRENGTH (DB)')
 1210 FORMAT (////,1X,'PRINTOUT OF POWER DENSITY AND ',           ..
     1'T.D.O.A. S AT X =',F8.2,2X,'NAUTICAL MILES',               ..
     2//5X,'NO.',8X,'HEIGHT (FT)',7X,'POWER DENSITY (DB)')        .
 1220 FORMAT (4X,I3,8X,F10.2,10X,E12.2)                           ..
      END                                                         ..
C                                                                 ..
```

```
C*************************************************************
C*************************************************************
      SUBROUTINE PLOTTR                                          ..
C                                                                ..
C-----THIS ROUTINE SETS UP THE AXES FOR ALL PLOTS.               ..
C                                                                ..
      IMPLICIT REAL*8(A-H,O-Z)                                   ..
      REAL*4 AHD,TTL,XTL,YTL,TLE                                 ..
      COMMON /TWOCCM/ RA,DELX,AHS,AHO,ELC(51),EXMAX,XFINAL      .
     1      ,JRAY                                                ..
      COMMON /THRCCM/ VX(30),YMIN,YMAX,XDIV,YDIV                 ..
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)          ..
     2      ,JPLT,KREF,KGRAD,KPLCT,JPLCT,IPLACE,JCASE,NELO       ..
     3      ,NREF,NRAY,NPRO,NPLCT,NGRAD,SCALE                    ..
      COMMON /FCRCCM/ DNDZ(100),RM(100),DMDZ(100),KMIR           ..
     1       ,KMGRAD,NMIR,NMGRAD,HF(100),DATCTL                  ..
      DIMENSION AHD(18),TTL(18),XTL(18),YTL(18),TLE(18)          ..
      DATA YSIZ,SIZE/5.0D0,1.505D-1/                             ..
      DATA IZTI,ZSIZ,ZMIN,ZDIV/10,1.0D0                          ..
     1,-2.0D1,4.0D1/                                             ..
C                                                                ..
C     SET UP INITIAL CONDITIONS IF THIS IS THE FIRST PLOT        ..
      IF (JPLT) 10,10,20                                         ..
   10 YDIV=(YMAX-YMIN)/YSIZ                                      ..
      YDIVA=YDIV/1000.0                                          ..
      YMINA=YMIN/1000.0                                          ..
      YPT=YSIZ+1.0                                               ..
      ZPT=YSIZ+0.5                                               ..
      YS=(AHS-YMIN)/YDIV                                         ..
      JPLT=1                                                     ..
C                                                                ..
C     READ PLOT SCALE FACTOR AND PLOT BANNER.                    ..
      READ 110,SCALE                                             ..
      READ 120,IAHD,(AHD(K),K=1,18)                              ..
```

```
C
C     INITIALIZE THE PLOTTER AND SCALE THE PLOT SIZE.
      CALL PLOTS (0,0,0)
      CALL PLOT (0.,0.,-999)
      CALL SETMSG (2)
      CALL FACTOR (SNGL(SCALE))
C
C     POSITION THE PEN AND PRINT THE PLOT BANNER.
   15 CALL PLOT (8.0,8.0,-3)
      CALL SYMBOL (0.0,0.0,SNGL(SIZE),AHD,00.0,IAHD)
C
C     POSITION THE PEN FOR THE NEXT PLOT.
      CALL PLOT (0.,0.,-999)
      CALL PLOT (2.0,2.0,-3)
      CALL FACTOR (SNGL(SCALE))
C
C     READ AXIS LABELS AND TWO LINES OF PLOT TITLES.
   20 READ 120,IXTL,(XTL(K),K=1,18)
      READ 120,IYTL,(YTL(K),K=1,18)
      READ 120,ITTL,(TTL(K),K=1,18)
      READ 120,ITLE,(TLE(K),K=1,18)
C
C     CHECK WHICH PLOT THIS IS.
      IF (JPLOT-5) 22,24,26
   22 CONTINUE
      IF (JPLOT-2) 30,40,60
C
C     SET UP INITIAL CONDITIONS FOR MODIFIED INDEX OF
C     REFRACTIVITY PROFILE AND GRADIENT PLOTS.
   24 CONTINUE
      XMAX = 520.0
      XMIN = 0.0
      GO TO 50
   26 CONTINUE
```

```
      XMAX = 350.0
      XMIN = 0.0
      GO TC 50
C
C     SET UP INITIAL CONDITIONS FOR REFRACTIVITY PROFILE
C     AND GRADIENT PLCTS.
   30 XMAX=400.0
      XMIN=0.0
      GO TC 50
   40 XMAX=200.0
      XMIN=-600.0
   50 XSIZ=4.0
      XDIV=(XMAX-XMIN)/XSIZ
      XDIVA=XDIV
      GO TC 70
C
C     SET UP INITIAL CONDITIONS FOR RAY TRACE, FIELD
C     STRENGTH, AND PCWER DENSITY PLOTS.
   60 XMAX=EXMAX
      XMIN=0.0
      XSIZ=10.0
      XDIV=(XMAX-XMIN)/XSIZ
      XDIVA=XFINAL/XSIZ
      XRE=XSIZ-C.5
C
C     SET UP PARAMETERS FOR AXIS LABELS AND PLOT TITLES.
   70 XTTL=(XSIZ-SIZE*ITTL)/2.
      XTLE=(XSIZ-SIZE*ITLE)/2.
C
C     DRAW AND LABEL THE AXES.
      CALL AXIS (0.0,0.0,YTL,IYTL,SNGL(YSIZ),90.0,
     1SNGL(YMINA),SNGL(YDIVA))
      CALL AXIS (0.0,0.0,XTL,-IXTL,SNGL(XSIZ),0.0,
     1SNGL(XMIN),SNGL(XDIVA))
```

```
C                                                               ..
C     PRINT THE PLOT TITLES.                                    ..
   74 CALL SYMBOL (SNGL(XTTL),SNGL(YPT),SNGL(SIZE),TTL,0.0,
     1ITTL)                                                     ..
      CALL SYMBOL (SNGL(XTLE),SNGL(ZPT),SNGL(SIZE),TLE,0.0,
     1ITLE)                                                     ..
C                                                               ..
C     DRAW THE REFERENCE SCALE FOR ALL FIELD STRENGTH AND       ..
C     POWER DENSITY PLOTS                                       ..
      IF (JPLOT-5) 78,82,82                                     ..
   78 CONTINUE                                                  ..
      IF (JPLOT-3) 82,82,80                                     ..
   80 CALL AXIS (SNGL(XRE),SNGL(ZPT),10H GAIN (DB),-IZTL,       .
     1SNGL(ZSIZ),0.0,SNGL(ZMIN),SNGL(ZDIV))                     ..
      CALL PLOT (SNGL(XSIZ),SNGL(ZPT),3)                        ..
      CALL PLOT (SNGL(XSIZ),SNGL(YPT),2)                        ..
   82 CALL PLOT (0.0,0.0,3)                                     ..
C                                                               ..
C     DRAW THE EARTH SURFACE IF NOT AT ZERO MEAN SEA LEVEL..
      IF (AHS-YMIN) 86,86,84                                    ..
   84 CALL PLOT (0.0,SNGL(YS),3)                                ..
      CALL PLOT (SNGL(XSIZ),SNGL(YS),2)                         ..
      CALL PLOT (0.0,0.0,3)                                     ..
C                                                               ..
C     POSITION THE PEN FOR THE REFRACTIVITY GRADIENT            ..
C     PROFILE PLOT.                                             ..
   86 CONTINUE                                                  ..
      IF (JPLOT-2) 88,90,88                                     ..
   88 CONTINUE                                                  ..
      IF (JPLOT-5) 100,90,90                                    ..
   90 XN= -XMIN/XDIV                                            ..
      CALL PLOT (SNGL(XN),0.0,-3)                               ..
  100 CONTINUE                                                  ..
  105 RETURN                                                    ..
```

```
C                                                                    ..
  110 FORMAT (3F15.7)                                                ..
  120 FORMAT (I2,8X,17A4,A2)                                         ..
      END                                                            ..
C                                                                    ..
C*********************************************************************
C*********************************************************************
      BLOCK DATA                                                     ..
C     SUBROUTINE BLOCK DATA.                                         ..
      IMPLICIT REAL*8(A-H,O-Z)                                       ..
      COMMON /ONECOM/ CRH,CRX,CRG,DTR,PHASE,THETA,C,C1,C2 ..
     1      ,RHO(51,30),PHI(51,30),PI,CMF,CNAUT,DENOT                ..
     2      ,FRQ,TPW,ABSRH,NHV,NSL,NRMS,JAREA,NDATA                  ..
      COMMON /TWOCOM/ RA,DELX,AHS,AHO,ELO(51),EXMAX,XFINAL .
     1      ,JRAY                                                    ..
      COMMON /THRCOM/ VX(30),YMIN,YMAX,XDIV,YDIV                     ..
     1      ,H(51,30),G(51,30),HN(100),RN(100),S(51,30)              ..
     2      ,JPLT,KREF,KGRAD,KPICT,JPLOT,IPLACE,JCASE,NELO  .
     3      ,NREF,NRAY,NPRO,NPLOT,NGRAD,SCALE                        ..
      DATA RHO,PHI/1530*0.D0,1530*0.D0/                              ..
      DATA ELO/51*0.D0/                                              ..
      DATA VX,H,G,HN,RN/30*0.D0,1530*0.D0,1530*0.D0,                 ..
     1100*0.D0,100*0.D0/                                             ..
      DATA S/1530*0.D0/                                              ..
      DATA DTR,RA,PI/1.7453D-02,2.0925D+07,3.14159D0/                ..
      DATA CMF,CNAUT/3.281D0,6.076D3/                                ..
      END                                                            ..
/*                                                                   ..
//GO.SYSIN DD *                                                      ..
    1                                                                ..
    0                                                                ..
    2                                                                ..
    8                                                                ..
 16250.         38.330                                               ..
```

```
2672.      233.401                                              ..
2595.      236.051                                              ..
1480.      274.486                                              ..
1466.      272.235                                              ..
 333.      314.985                                              ..
  72.      351.813                                              ..
  23.      357.481                                              ..
  75.45     90.                                                 ..
  70.00   5000.                                                 ..
  20.00    200.00                                               ..
   0.50    -0.50                                                ..
2900.00     6.50                                                ..
  1    2    3                                                   ..
  1    1    0    0    1    1                                    ..
  1    1    1    1    1    1                                    ..
          1.00                                                  ..
12        19 APR 1984                                           ..
22        REFRACTIVITY (N-UNITS)                                ..
38        HEIGHT ABOVE EARTH (THOUSANDS OF FEET)                ..
32        ATMOSPHERIC REFRACTIVITY PROFILE                      ..
42        DHAHRAN, SAUDI ARABIA - 1 MAY 1978, 0000Z             ..
34        REFRACTIVITY GRADIENT (N-UNITS/KM)                    ..
38        HEIGHT ABOVE EARTH (THOUSANDS OF FEET)                ..
29        REFRACTIVITY GRADIENT PROFILE                         ..
42        DHAHRAN, SAUDI ARABIA - 1 MAY 1978, 0000Z             ..
40        MODIFIED INDEX OF REFRACTIVITY (M-UNITS)              ..
38        HEIGHT ABOVE EARTH (THOUSANDS OF FEET)                ..
38        MODIFIED INDEX OF REFRACTIVITY PROFILE                ..
42        DHAHRAN, SAUDI ARABIA - 1 MAY 1978, 0000Z             ..
42        MOD INDEX OF REFRAC GRADIENT (M-UNITS/KM)             ..
38        HEIGHT ABOVE EARTH (THOUSANDS OF FEET)                ..
43        MOD INDEX OF REFRACTIVITY GRADIENT PROFILE            ..
42        DHAHRAN, SAUDI ARABIA - 1 MAY 1978, 0000Z             ..
```

```
37         DISTANCE ALONG EARTH (NAUTICAL MILES)                 ..
38         HEIGHT ABOVE EARTH (THOUSANDS OF FEET)                ..
56         RAY TRACE FOR DHAHRAN, SAUDI ARABIA -                 ..
            *LINE CON'T*    1 MAY 78, 0000Z                      ..
56         HO =     90 FT    RAY ANGLES FROM -0.5 TO  0.50       ..
            *LINE CON'T*    DEGREES                              ..
37         DISTANCE ALONG EARTH (NAUTICAL MILES)                 ..
38         HEIGHT ABOVE EARTH (THOUSANDS OF FEET)                ..
58         REL FLD STR - DHAHRAN,SAUDIA ARABIA -                 ..
            *LINE CON'T*    1 MAY 78, 0000Z                      ..
56         HO =     90 FT    RAY ANGLES FROM -0.5 TO  0.50       ..
            *LINE CON'T*    DEGREES                              ..
C***********************************************************************
C***********************************************************************
EXAMPLE OF THE OTHER DATA SET:                                   ..
    1                                                            ..
    1                                                            ..
    2                                                            ..
    9                                                            ..
 16550.000     38.939  2637.287     -6.760    150.238            ..
  3161.000    203.493   699.770    -19.978    137.021            ..
  2478.000    217.138   606.184     -5.109    151.892            ..
  2209.000    218.512   565.325    -30.442    126.558            ..
  1488.000    240.461   474.077    -41.159    115.841            ..
   627.000    275.899   374.338    -34.524    122.477            ..
   374.000    284.634   343.351   -164.929     -7.929            ..
    49.000    338.235   345.928     26.602    183.603            ..
    23.000    337.544   341.155    200.000    350.000            ..
    75.45      90.                                               ..
    70.00    5000.                                               ..
    20.00     200.00                                             ..
     0.50     -0.50                                              ..
  9800.00    1340.00                                             ..
    1    2    3                                                  ..
```

```
      1    0    0    0    0    0                              ..
      1    1    1    2    1    1                              ..
               1.00                                           ..
12            26 APR 1984                                     ..
22            REFRACTIVITY (N-UNITS)                          ..
38            HEIGHT ABOVE EARTH (THOUSANDS OF FEET)          ..
32            ATMOSPHERIC REFRACTIVITY PROFILE                ..
42            DHAHRAN, SAUDI ARABIA - 23 MAY 1978, 0000Z      ..
34            REFRACTIVITY GRADIENT (N-UNITS/KM)              ..
38            HEIGHT ABOVE EARTH (THOUSANDS OF FEET)          ..
29            REFRACTIVITY GRADIENT PROFILE                   ..
42            DHAHRAN, SAUDI ARABIA - 23 MAY 1978, 0000Z      ..
40            MODIFIED INDEX OF REFRACTIVITY (M-UNITS)        ..
38            HEIGHT ABOVE EARTH (THOUSANDS OF FEET)          ..
38            MODIFIED INDEX OF REFRACTIVITY PROFILE          ..
42            DHAHRAN, SAUDI ARABIA - 23 MAY 1978, 0000Z      ..
42            MOD INDEX OF REFRAC GRADIENT (M-UNITS/KM)       ..
38            HEIGHT ABOVE EARTH (THOUSANDS OF FEET)          ..
43            MOD INDEX OF REFRACTIVITY GRADIENT PROFILE      ..
42            DHAHRAN, SAUDI ARABIA - 23 MAY 1978, 0000Z      ..
37            DISTANCE ALONG EARTH (NAUTICAL MILES)           ..
38            HEIGHT ABOVE EARTH (THOUSANDS OF FEET)          ..
56            RAY TRACE FOR DHAHRAN, SAUDI ARABIA -           ..
               *LINE CON'T*   23 MAY 78, 0000Z                ..
56            HO =     90 FT    RAY ANGLES FROM -0.5 TO  0.50 ..
               *LINE CON'T*    DEGREES                        ..
37            DISTANCE ALONG EARTH (NAUTICAL MILES)           ..
38            HEIGHT ABOVE EARTH (THOUSANDS OF FEET)          ..
58            REL FLD STR - DHAHRAN,SAUDIA ARABIA -           ..
               *LINE CON'T*   23 MAY 78, 0000Z                ..
56            HO =     90 FT    RAY ANGLES FROM -0.5 TO  0.50 ..
               *LINE CON'T*    DEGREES                        ..
C**************************************************************
C**************************************************************
```

LIST OF REFERENCES

1. *The Military Balance 1976-77*, p. 78, The International Institute for Strategic Studies, 1976.

2. *The Military Balance 1980-81*, p. 96, The International Institute for Strategic Studies, 1980.

3. *The Military Balance 1983-84*, pp. 13 & 126, The International Institute for Strategic Studies, 1976.

4. *The Europa Year Book 1983 - A World Survey*, v. II, p. 1347, Europa Publications Limited, 1983.

5. *Collier's Encyclopedia*, v. 20, p. 381, Macmillian Educational Corporation and P.F. Collier, Inc., 1980.

6. *Minerals Yearbook 1974*, v. II, p. 2, Bureau of Mines, US Department of the Interior, 1976.

7. *Minerals Yearbook 1974*, v. III, pp. 464, 474, 595, 602, 931, & 1010, Bureau of Mines, US Department of the Interior, 1976.

8. *Minerals Yearbook 1980*, v. III, pp. 494, 504, 614, 845, 1106, & 1030, Bureau of Mines, US Department of the Interior, 1982.

9. *The World Almanac and Book of Facts 1982*, p. 130, Newspaper Enterprise Association, Inc., New York, 1982.

10. *The Europa Year Book 1983 - A World Survey*, v. II, p. 1346, Europa Publications Limited, 1983.

11. Davidson, K., Class notes for MR2416, Naval Postgraduate School, Monterey, CA, p. 7-2, Winter Semester 1983.

12. Kelly, J.A., "The Soviet Threat In Asia", *Defense*, pp. 14-23, January 1984.

13. Davidson, K., Class notes for MR2416, Naval Postgraduate School, Monterey, CA, p. 3-4, Winter Semester 1983.

14. Ibid., pp. 3-1 - 3-18.

15. Ibid., pp. 4-1 - 4-4.

16. Ibid., p. 4-5.

17. Ibid., p. 4-5.

18. Ibid., p 4-7.

19. Ibid., p. 4-8.

20. Ibid., p. 4-8.

21. Ibid., p. 3-9.

22. Ibid., p. 4-15.

23. Compendium of Meteorology, p. 655-662, American Meteorological Society, 1951.

24. Ibid., p. 656.

25. Collier's Encyclopedia, v.2, pp. 377-392, Macmillian Educational Corporation & R.F. Collier, Inc., 1980.

26. Wernstedt, F.I., World Climatic Data, p. 278, Climatic Data Press, 1972.

27. World Survey of Climatology, 15 vol., Elsevier Scientific Publishing Company, Amsterdam, Oxford, New York: v.9, "Climates of Southern & Western Asia", pp 233-247, 1981.

28. Ibid., p. 251.

29. Pilot Charts of the Indian Ocean, 1st ed., pp, 5 & 10, Defense Mapping Agency Hydrographic/Topographic Center, 1979.

30. World Survey of Climatology, 15 vol., Elsevier Scientific Publishing Company, Amsterdam, Oxford, New York: v.9, "Climates of Southern & Western Asia", pp 215-219, 1981.

31. Ortenburger, L.N., Lawson, S.B., and Miller, G.K., Radiosonde Data Analysis III Summary Maps of Observed Data, Region 4 Map 1, GTE Sylvania Incorporated, 31 December 1978.

32. Ibid., Region 4 Map 3.

33. Ibid., Region 4 Map 4.

34. Ibid., Region 4 Map 6.

35. Ibid., Region 4 Map 7.

36. Ibid., Region 4 Map 9.

37. Ibid., Region 4 Map 11.

38. Ibid., Region 4 Map 12.

39. Kasky, R.P., A Geometric Optics Model for Calculating the Field Strength of Electromagnetic Waves in the Presence of Tropospheric Duct, M.S. Thesis, University of Dayton, Ohio, December 1977.

40. Skolnik, M.I., Introduction to Radar Systems, 2nd ed., pp. 1-14, McGraw-Hill Book Company, 1980.

41. Jane's Weapons Systems 1983-84, 14th ed, pp. 464-485, Jane's Publishing Company Limited, London and New York, 1983.

BIBLIOGRAPHY

Collier's Encyclopedia, v. 8, pp. 475-485, Macmillian Educational Corporation and P.F. Collier, Inc., 1980.

Collier's Encyclopedia, v. 18, p. 629, Macmillian Educational Corporation and P.F. Collier, Inc., 1980.

Hughes, V.C., "The Airlift Stepchild: What Happened to Tactical Airlift Modernization?", Armed Forces Journal International, pp. [illegible]7-99, October 1983.

Meyer, E.C. General, "A Ready Land Force", Defense, pp. 2-9, April 1[illegible].

Saudi Arabia - The Kingdom and Its Power, pp. 286-332, National Geographic, September 1980.

The Europa Year Book 1983 - A World Study, v.2, Europa Publications Limited, 1983.

Weinberger, C.W., "The Reality of the Soviet Threat", Defense, pp. 2-7, June 1983.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943	2
3.	Professor John M. Bouldry, Code 73 Chairman, Electronic Warfare Academic Group Naval Postgraduate School Monterey, California 93943	2
4.	Professor Kenneth L. Davidson, Code 63Ds Department of Meteorology Naval Postgraduate School Monterey, California 93943	2
5.	Professor Jeffrey M. Knorr, Code 62Ko Department of Electrical and Computer Engineering Naval Postgraduate School Monterey, California 93943	2
6.	Cpt. (F) Wayne F. Petersen 345 Weatherbee Road Lot #18 Ft. Pierce, Florida 33450	1

END

FILMED

5-85

DTIC